GE Energy

David H. Hinds
Manager, ESBWR

PO Box 780 M/C L60
Wilmington, NC 28402-0780
USA

T 910 675 6363
F 910 362 6363
david.hinds@ge.com

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Subject: **Response to Portion of NRC Request for Additional Information Letter No. 31 Related to ESBWR Design Certification Application – TRACG Application for ESBWR ATWS - RAI Numbers 21.6-7, 21.6-10, 21.6-11, 21.6-13 through 21.6-26, and 21.6-30 through 21.6-32**

Enclosure 1 contains GE's response to the subject NRC RAIs transmitted via the Reference 1 letter.

If you have any questions about the information provided here, please let me know.

Sincerely,

Kathy Sedney for

David H. Hinds
Manager, ESBWR

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Enclosure:

1. MFN 06-208 - Response to Portion of NRC Request for Additional Information Letter No. 31 Related to ESBWR Design Certification Application – TRACG Application for ESBWR ATWS - RAI Numbers 21.6-7, 21.6-10, 21.6-11, 21.6-13 through 21.6-26, and 21.6-30 through 21.6-32

Reference:

1. MFN 06-203, Letter from U. S. Nuclear Regulatory Commission to Mr. David H. Hinds, *Request for Additional Information Letter No. 31 Related to ESBWR Design Certification Application,* June 23, 2006

cc:	WD Beckner	USNRC (w/o enclosures)
	AE Cubbage	USNRC (with enclosures)
	LA Dudes	USNRC (w/o enclosures)
	GB Stramback	GE/San Jose (with enclosures)
	eDRF	0000-0054-2289

ENCLOSURE 1

MFN 06-208

Response to Portion of NRC Request for Additional Information Letter No. 31 Related to ESBWR Design Certification Application TRACG Application for ESBWR ATWS RAI Numbers 21.6-7, 21.6-10, 21.6-11, 21.6-13 through 21.6-26, and 21.6-30 through 21.6-32

NRC RAI 21.6-7

On Page 5-2, you state that the Coanda effect is neglected. It is not clear to the staff how neglecting this phenomenon is conservative. Since the Coanda effect would result in a greater degree of azimuthal solution flow, it may take longer for the borated solution to settle to the bottom of the bypass region for two reasons: (1) the fluid is traveling azimuthally and is not interacting with the channel box to form a plume, and (2) the fluid is interacting with a larger portion of the bypass and may heat up as a result, such that the temperature difference between the fluids is smaller. Provide detailed justification as to how neglecting the Coanda effect is conservative.

GE Response

Neglecting the Coanda effect is conservative because the Coanda effect would result in a greater spreading of the boron along the periphery of the shroud wall and consequently a greater effect on the boron reactivity. The borated water is also simultaneously being transported downward because of the downward bulk flow in the peripheral bypass. No credit is taken in the analysis for a reduction in transport time of the boron because of the higher density of the borated solution. The sensitivity to peripheral spreading is explored by considering the spreading of the boron in the narrow sectors vs. the large sectors in response to RAI 21.6-8.

NRC RAI 21.6-10

On Page 5-3, using Figure 5.1-1, you state that the distance from the jet inlet nozzle to the fuel channel box is estimated based on concentric circles. Has this distance been explicitly calculated based on the core orientation relative to the inlet nozzles? What is the difference between the estimate and the exact values? How does this difference affect the calculated jet parameters?

GE Response

The distance from the jet inlet nozzle to the fuel channel box was estimated based on concentric circles to be 51 cm. Considering the actual layout of the channel boxes, and the orientation of the nozzles in the current design, this distance will be 45.3 cm. The corresponding temperatures in the jet at the channel box boundary will change from 287.6 to 286.0 C. The plume temperatures at the bottom of the bypass will change from 290.4 to 289.6 C. None of the conclusions from the jet analysis are affected.

NRC RAI 21.6-11

While density differences is what drives the downward flow of the borated solution, you state on Page 5-3 that the "density difference corresponding to the different temperature is not accounted for in the mass and momentum balances [for the equations describing the circular turbulent jet characteristics, and] Hence, this solution must be considered approximate when there are large differences between the injected and ambient densities." At what value in density difference does this solution become approximate? Compare this with the assumed density differences between the injected solution and the ambient liquid. If the density difference is great enough that the solution is considered "approximate," what uncertainties are added to maintain a conservative solution? Provide clarifying information on what is meant by: "Accordingly, we use only the expression for the entrained volume of ambient liquid, but calculate the temperatures and densities using mass and energy balances."

GE Response

It is appropriate to preface the response to the specific question and some of those that follow with some explanation of what role the jet mixing analysis plays in the overall TRACG calculations. The jet mixing analysis is intended to be an order of magnitude analysis to provide some insight into the physical phenomena related to boron mixing and transport. The insights gained from the analysis are used to ensure that the TRACG model is both reasonable and conservative with respect to the calculation of boron reactivity. It is not intended to be a precise analysis to be subjected to a quantitative uncertainty analysis; uncertainties will be addressed directly as part of the TRACG analysis. The following general conclusions can be drawn from the results of the jet mixing model:

1. There is good mixing due to the high velocity jets. The injected solution reaches close to ambient temperature (and density) near the injection location. The TRACG assumption of complete mixing within the injected cell is reasonable.
2. It is not likely that a significant portion of the horizontally injected jet would penetrate through the 'open channel' between bundles. The orientation of the nozzles is designed to achieve rapid mixing rather than penetration into the inner region through gaps between channels. It is assumed that no boron gets through to the interior region. This restriction is modeled in TRACG by isolating the peripheral ring, which is a conservative assumption. (The effect of the reactivity in the peripheral bundles needs to be examined through TRACG sensitivity studies).
3. The falling plumes do not spread much as they fall. This is modeled in TRACG by restricting the boron to sectors in the peripheral ring. The sensitivity to the sector size will be explored through TRACG sensitivity studies.
4. The maximum temperature deficit in the borated solution is of the order of 10 degrees by the time it gets to the bottom of the bypass. It is expected that thermal mixing will rapidly reduce the density gradient and prevent stratification and sinking into the bundle lower tieplate at these low temperature differences. An

extremely conservative (in this application) CCFL criterion is used to calculate a critical Froude Number for stratification to occur. This criterion will be used as one means of evaluating the overall conservatism in the TRACG analysis. It may be noted that stratification at the top of the guide tube is not an issue because the flow at that location is calculated to be downwards in TRACG

The initial injected boron solution is in the form of a high velocity (34 m/s) horizontal jet. This jet travels to the outer row of channels in a fraction of a second. Vertical motion of the jet can be ignored relative to the horizontal distance traveled by the jet. Under these conditions, the Reference 1 momentum equations governing the jet motion (Eq. 9-1 through 9-11) and the data used to derive the empirical constants, which do not explicitly consider the effect of density differences between the jet and the entrained fluid, may be applied to the ESBWR where the jet and the ambient fluid have different temperatures but the average density difference along the jet path length is not a large fraction of the individual densities. The jet entrains ambient fluid at the jet boundary (intermittency surface) through turbulent fluctuations in the velocities. A solution of the above equations can be obtained in terms of the eddy viscosity for turbulence. Experimental data are combined with the form of the theoretical solution to obtain the jet equations in Table 9-3. The solution did not explicitly consider differences in density between the jet and entrained fluid. It was assumed in the GE calculations that volumetric entrainment rates driven by turbulence at the jet boundary would not be affected due to the density differences. This is a reasonable assumption, which is used in other mixing applications, e.g. two-phase subchannel mixing (Kazimi & Kelly, Formulation of Two-Fluid Model for Mixing in LWR Bundles, Thermal Hydraulics of Nuclear Reactors, Vol 1, pp 433-439, ANS, 1983). The total jet volumetric flow (Q) is essentially the only parameter used from Table 9-3. When the volume of the jet flow is known, the average properties of the jet can be calculated at the channel boundary through simple mass and energy balances. The volume of fluid entrained into the jet $Q_{induced} = Q - Q_0$, where Q_0 is the initial jet flow at the orifice. The mass flow in the jet = $Q_0 \times \square_0 + Q_{induced} \times \square_a$, where $\square_0$ is the initial jet density and $\square_a$ is the density of the ambient fluid being entrained into the jet.
The average enthalpy of the jet is $(Q_0 \times \square_0 \times h_o + Q_{induced} \times \square_a \times h_a)/(Q_0 \times \square_0 + Q_{induced} \times \square_a)$, where h_o and h_a are the initial jet enthalpy and the ambient fluid enthalpy, respectively.
To provide further confirmation of the adequacy of the above procedure, the information from Reference 2 has been utilized. Reference 2 provides empirical data for submerged jet entrainment when the initial jet density is different from the ambient density. Three combinations were studied: air injected into air; carbon dioxide injected into air (density ratio 1.5); and hydrogen injected into air (density ratio 0.04). The jet mass flow M could be correlated in terms of the initial volumetric flow Q_0 for all cases as:

$$\frac{M}{Q_0\sqrt{\rho_0\rho_a}} = 0.16\frac{x}{r_0}$$

Note that this reduces to the formula for Q in Table 9-3 of Reference 1 when $\square_a = \square_0$.

Using this expression for the entrained mass, together with the more accurate distance of 45.3 cm for the length of the jet, the jet temperature at the channel boundary changes from 287.6 to 288.3 C. None of the conclusions from the jet analysis are affected.

There is no allowance for uncertainties to ensure a 'conservative' solution. It was not considered necessary for an order of magnitude analysis. Please refer to the above discussion of how the analysis results are used.

References:

1. R. D. Blevins, Applied Fluid Dynamics Handbook, Krieger Publishing Company (2003)
2. F. P. Ricou and D. B. Spalding, Measurement of Entrainment by Axisymmetric Turbulent Jets, Journal of Fluid Mechanics, 11, pp. 21-32 (1961).

NRC RAI 21.6-13

On Page 5-4, you use a value of 34.2 m/s for the jet initial velocity (Uo) however on Page 8-1 you state the "average velocity at the flow nozzles that inject the solution into the bypass region is 30.5 m/s during the first half of the injection." Why are these two values different? What is the sensitivity to jet initial velocity to your calculated jet properties? What is the sensitivity to jet initial velocity on your TRACG calculations?

GE Response

The value of 34.2 m/s corresponds to the initial velocity of the borated water jets for a downstream pressure of 8.72 MPA versus the requirement that the first half of the volume required for hot shutdown conditions be injected at an average velocity of 30.5 m/s. Using a value of 30.5 m/s in the jet calculations results in no change in the average jet temperature at the channel box boundary. The induced flow is proportional to the injected flow and average temperature is unchanged at 287.6 C. The plume flow will be slightly smaller and the calculated temperature at the bottom of the bypass is 290.7 C instead of 290.4 C. None of the conclusions from the jet analysis are affected.

NRC RAI 21.6-14

On Page 5-4, you calculate the distance along the jet should be less than 1.14m for the jet to retain jet-like behavior. Since you estimate the distance along the jet centerline from the shroud wall to the channel boundary is 0.5m (something less than 1.14m) you assume that the jet retains jet-like behavior. Is this true? What is the uncertainty for the calculation of the 1.14m value?

GE Response

The expression for transition from jet to plume behavior cited in this section of the report is intended for application to vertical jets and plumes. As such it is not relevant to the horizontal jet that emanates from the injection orifice. Reference to this criterion will be deleted from this section. There is no maximum distance for the transition of a horizontal jet to a plume. It is clear that the jet will still be traveling with a significant velocity (> 2 m/s) at the channel boundary and will retain its jet like properties.

NRC RAI 21.6-15

On Page 5-4, you state that "because the jet fluid is also heavier than the surrounding fluid, the jet will likely droop, resulting in longer distance between the discharge and the channel boundary." Has the uncertainty due to this droop been added to the calculated length of the jet?

GE Response

The jet inlet velocity is 34 m/s. By the time the jet reaches the channel boxes, the velocity has dropped to 2 m/s. Assuming a mean velocity of the order of 17 m/s, the jet takes less than 0.05 s to cover the distance of 0.5 m to the channel boxes. Any vertical droop in this fraction of a second is negligible.

NRC RAI 21.6-16

On Page 5-4, you calculate the properties of the "well-mixed region" by "averaging the jet conditions at the channel boundary." Explain how this is done. Which conditions are averaged? Define the variables, include definitions for: Mo, Qo, ho, Minduced, Mtotal, Qch.

GE Response

Please also see the response to RAI 21.6-11.
Q_0 is the initial volumetric jet flow out of the orifice; M_0 is the initial mass flow rate in the jet, given by Q_0 x $\square_0$, where $\square_0$ is the initial jet density. Q_{ch} is the volumetric flow in the jet when it reaches the boundary of the peripheral channels (obtained from the equation in Table 9-3); $Q_{induced}$ is the entrained volumetric flow in the jet given by (Q_{ch} - Q_0). $M_{induced}$ = mass flow entrained by the jet = $Q_{induced}$ x $\square_a$, where $\square_a$ is the density of the ambient fluid being entrained into the jet M_{total} = mass flow in the jet at the channel boundary, given by (M_0 + $M_{induced}$).

NRC RAI 21.6-17

You calculate the average temperature deficit as 13oC on Page 5-4. What is the range of this value given all of the uncertainties in the input parameters used to calculate it? It appears as though this value is used to determine that the plume will have negative buoyancy. Is this true? At what value of the temperature deficit will the plume no longer have negative buoyancy?

GE Response

Properties of submerged jets are well established. The calculations follow accepted formulae for jet entrainment based on the solution of integral equations of motion for the jet. The only additional assumption made is that volumetric mixing rates will remain the same with density differences of the magnitude of 40%. This assumption was compared with a more accurate correlation in response to RAI 21.6-11 and shown to be reasonable. Changes in input parameters such as the jet velocity and distance to the channel boxes produced changes in the temperature deficit at the channel boxes of the order of 1 C. Even changing the density of the injected fluid to be equal to that in the bypass (a change of 40%), only changed the temperature deficit from 13 to 9 C. The primary use of the calculation of the temperature deficit of 13 C is to confirm that the cell in which TRACG injects the borated solution is well mixed and that the borated water warms up to close to ambient temperature quickly. The accuracy of the calculation is sufficient to support that conclusion.

The value of 13 C is also used in the estimation of the temperature of the boron plume at the bottom of the bypass for the calculation of stratification in the lower tieplate nosepieces. As explained in later responses, the plume entrainment is treated conservatively to maximize the temperature deficit at the bottom of the bypass.

The plume will have negative buoyancy as long as its temperature is lower than the ambient bypass temperature.

NRC RAI 21.6-18

On Page 5-4, you use the following relationship to determine if the jet will retain jet-like behavior or behave like a buoyant plume:

$X_j < \quad {}_o^{3/4} / B^{1/2}$

From reviewing your Reference 36, R.D. Blevins, Applied Fluid Dynamics Handbook, the origin of this equation is not clear. Please explain its origin, along with justifying its applicability to ESBWR ATWS conditions (i.e. jet in cross-flow, negatively buoyant jet, etc.)

GE Response

Please see the response to RAI 21.6-14. The use of the relationship to calculate a transition from jet like behavior to plume like behavior is applicable to vertical buoyant jets. Its use is not appropriate for the initial horizontal jet, nor is it needed. Reference to this correlation on Page 5-4 will be deleted.

NRC RAI 21.6-19

On Page 5-5, you state that "Tests have been performed in large downcomers with upward flow of a light species (gas) and downward flow of liquid. Downward liquid penetration was shut off when the square root of the gas Froude number is of the order of 0.14. If we assume a similar critical Froude number for the situation of liquid/liquid countercurrent flow..." Justify the assumption that the test data is valid for this situation.

GE Response

The Froude Number criterion for plume downflow in the peripheral bypass was developed for the sake of completeness. Because the velocity in the peripheral bypass is downwards, the Froude number criterion is not needed and never invoked.

NRC RAI 21.6-20

On Page 5-5, you define a value, B, for specific buoyancy flux. You define this as:

$$Q_{ch} g(\rho_{ave} - \rho_{bypass}) / \rho_{bypass}$$

This is similarly defined in equation 9-50 in your Reference 36, R.D. Blevins, Applied Fluid Dynamics Handbook as:

$$Q_0 g(\rho_a - \rho_0) / \rho_a$$

Please explain the discrepancy. How does the length at which the plume has not spread change if you use $_{ave}$ *in the denominator when calculating B? Address this issue for determining the length jet-like behavior will persist for the leakage into the nosepiece calculation on Page 5-7.*

GE Response

The nomenclature in Blevins refers to the ambient condition outside the plume with subscript 'a' and the initial conditions within the plume with the subscript '0'. In the application to the bypass region, the ambient condition has the subscript 'bypass' and the conditions at the initiation of the plume, the subscript 'ave'. Hence, the equivalent expression for Blevins equation 9-50 becomes

$$Q_{ch} g(\rho_{bypass} - \rho_{ave}) / \rho_{bypass}$$

Because we are considering negatively buoyant plumes, this expression will have a negative value. For negatively buoyant plumes, the driving specific buoyancy flux is the negative of the above expression or

$Q_{ch} g(\rho_{ave} - \rho_{bypass}) / \rho_{bypass}$, as correctly stated on Page 5-5.

NRC RAI 21.6-21

You use the following equation on Page 5-5 to calculate the length at which the plume has not spread:

$X_j = {}^{3/4} / B^{1/2}$

From reviewing your Reference 36, R.D. Blevins, Applied Fluid Dynamics Handbook, the origin of this equation is not clear. Please explain its origin, along with justifying its applicability to ESBWR ATWS conditions. Are you using this to calculate the length of the nonspreading plume after it has impinged on the channel wall? Is this equation applicable for those conditions?

GE Response

The criterion stated above is used in Blevins to determine the transition from jet-like to plume–like behavior. The ratio of the volumetric flow in a plume to that in a jet varies as:

$$\frac{Q_{plume}}{Q_{jet}} = \left(\frac{xB^{2/3}}{\Pi_0^{3/4}}\right)^{2/3}$$

As the axial distance x from the origin increases, the volume flow in a plume with buoyancy B substantially exceeds that of a nonbuoyant jet with initial momentum flux □and the buoyant jet becomes increasingly plume-like. Because entrainment of ambient fluid from the bypass reduces the temperature deficit of the plume, no credit is taken for entrainment prior to the jet reaching plume-like behavior.

After the initial horizontal jets have collided with the channel boxes, the horizontal momentum is dissipated resulting in a well-mixed region near the point of impact. The mass of fluid brought in by the jet is treated as a source for a negatively buoyant plume. The spreading of the plume is calculated by the equations in Table 9-7 of Reference 1. These equations are for fully developed plumes. The plumes become more turbulent as they move downwards because the momentum of the plume is constantly augmented by buoyancy-induced momentum. The criterion given by Blevins in Equation 9-55 was used to judge whether the plume had become fully developed based on satisfying the requirements for 'plume like' behavior. The transition from submerged-jet like behavior to plume like behavior is marked by increased entrainment and a change in the slope of the temperature deficit versus distance as shown in Figure 9-16 of Reference 1. The smaller the entrainment into the plume, the larger is the temperature deficit in the plume. The primary purpose of this part of the analysis is the calculation of a maximum credible temperature deficit when the plume reaches the bottom of the bypass. Hence, it was decided to conservatively ignore any entrainment prior to the plume reaching 'plume like' behavior. This means that the plumes originating from the lower injection locations do not entrain any ambient fluid and reach the bottom of the bypass with the full temperature deficit (~13 C) reached at the end of the horizontal jet mixing.

NRC RAI 21.6-22

On Page 5-5, you calculate the distance at which the plumes would not spread. You calculate this distance to be 1.08 m, this is a sizeable fraction of the total core height (~ 3m). How is this value used in the TRACG calculations? Assuming the plumes do not spread for this distance appears to be non-conservative as a greater degree of spreading of the plume will slow the transport of boron to the lower core plate as well as further reduce the temperature deficit. Please provide justification that this value is being used in a conservative manner.

GE Response

As explained above, the purpose of the plume analysis is to calculate the maximum credible temperature deficit when the boron reaches the bottom of the bypass, with the objective of maximizing the potential for stratification. Smaller spreading and mixing of the plumes (e.g., by not accounting for any entrainment over the first 1.08m of downward travel) therefore leads to a conservative analysis. The analysis has no bearing on the transport time, which is calculated by TRACG using its node structure and liquid phase velocities.

NRC RAI 21.6-23

On Page 5-6, you state that "if the plumes from the four different elevations are assumed not to interact with each other, the volumetric flow rates in the plumes when they reach the bottom of the bypass can be calculated from the above table." The above table then references equations for "circular plume characteristics." This is contradictory to a statement on 5-2, where you state that "the plumes sinking from the top injection point will interact with those directly below." Justify the assumption that the plumes do not interact with each other. Provide details explaining the conservative or non-conservative nature of this assumption.

GE Response

The upper plumes might be expected to interact with and have some influence on the plumes directly below. In the calculations, a linear superposition model is used, where the plumes are considered separately and their flow rates are added. This is a common engineering approximation, given the fact that interaction effects are generally of second order.

NRC RAI 21.6-24

On Page 5-6, you calculate the volume flow rate for the four plumes. Why is the volumetric flow rate highest for the top plume?

GE Response

The top plume falls for the greatest distance and consequently is able to entrain more liquid from the bypass region.

NRC RAI 21.6-25

It appears as though the equations you used on Page 5-6 from Reference 36, R.D. Blevins, Applied Fluid Dynamics Handbook from Table 9-7, p. 250, were developed for a vertical buoyant plume. Please explain how this is applicable for the ESBWR ATWS conditions in which the plumes form after the jet impinges on the channel wall and travels downward.

GE Response

The equations in Blevins are for a vertical upward buoyant plume. A plume is formed due to density differences, starting with a close-to-zero velocity. It is assumed that following impingement on the channel walls, there is a well-mixed region with zero vertical velocity, that moves downwards relative to the bulk motion due to density differences. This is a plume with negative buoyancy. It is a reasonable assumption that a plume with negative buoyancy will spread in the downward direction in a similar manner as an upward buoyant plume, because both are governed by turbulent entrainment driven by the density difference. The idea of this order of magnitude analysis is to estimate the maximum subcooling of the plumes to bound the loss of boron due to stratification effects in the lower tieplate. The subcooling changes from 13 to 10 C in the plumes. The maximum value of the subcooling is bounded by the initial 13 C.

NRC RAI 21.6-26

On Page 5-6, you make the assumption that the plumes do not interact however you average them and calculate an "average temperature deficit" to determine if the borated solution will spread at the bottom of the bypass. Explain this discrepancy. Explain in more detail how the calculated density difference determines if the borated solution will spread peripherally and radially. How does this change if you do not average the plumes?

GE Response

The flows from the four plumes from the four elevations are added together and the properties averaged. This is the established procedure for a linear superposition analysis. The temperature deficit is not used to determine whether the plumes will spread at the bottom of the bypass. The value of the temperature deficit is only used to examine the likelihood of stratification at selected locations. The value calculated at the bottom of the plumes is used directly as a maximum credible value for this purpose. In reality, this temperature deficit will decrease as the diluted boron solution spreads along the core support plate.

The simple jet/plume model is not used beyond the point where the plumes reach the bottom of the bypass. TRACG calculates radial and axial velocities based on its node structure, using average properties (velocities, pressure, density, temperature, boron concentration). The temperature deficit output from the jet model is used to evaluate possible stratification effects that might be missed in TRACG if TRACG calculates small upward bulk fluid velocities. A range of small upward velocities is calculated based on a limiting Froude number, where it might be possible that a heavier fluid could sink against bulk upward motion.

RAI 21.6-30

On Page 5-7, when discussing the leakage flow entering the channel inlet region you make reference to jet-like behavior and use the equation to determine the length jet-like behavior will persist. Please clarify exactly where this jet-like behavior will occur and justify the assumption that it will indeed be jet-like. Justify the use of the equation above given the conditions in the ESBWR leakage into the nosepiece.

GE Response

Please refer to the figure of the lower tieplate/nosepiece and the leakage paths in Figure 21.6-29-1. Approximately 60% of the flow comes through two 7 mm holes in the sides of the nosepiece. The direction of the flow through the holes is about 45 degrees to the horizontal in the upward direction. The remaining 40% of the leakage is through narrow gaps between the bottom of the channel and the lower tieplate. This is a tortuous path where the flow first goes upwards, turns around and discharges downwards into the nosepiece below the lower tieplate. The leakage flow will be heated up through this leakage path by contact with the metal surfaces around the narrow gap and the small subcooling at the entrance will be dissipated. Nevertheless, the flows through both leakage paths were combined and an equivalent hydraulic diameter was defined for the discharge passage based on the total area and perimeter of the leakage paths. Essentially, the two holes and the narrow annulus gap are being represented by an equivalent set of circular openings of diameter 3 mm. The maximum distance traveled by these discharging jets is of the order of 4 cm, i.e the distance from the periphery to the center of the nosepiece. The transition to plume like behavior occurs when the jet velocity drops to essentially zero. This distance is calculated to be of the order of 10 cm, and there is a considerable margin for error with respect to the maximum distance traveled of 4 cm. Another, perhaps more realistic approach to this problem, would be to ignore the leakage through the channel to tieplate path, as it would not retain any subcooling by the time it enters the nosepiece. Then, the subcooled flow would only be through the two holes of diameter of 7 mm. Considering a jet of initial diameter of 7 mm, the jet temperature at the center of the nosepiece has a temperature deficit of 5.3 C instead of 2.2 C. The corresponding critical velocity based on the CCFL correlation would be 10.9 cm/s; however, this would apply to only 60% of the boron entering the nosepiece.
As mentioned earlier, application of a CCFL correlation when the difference in temperatures and densities is so small is overly conservative. A CFD calculation is being done to get a more realistic estimate of the effect of stratification in the nosepiece.

NRC RAI 21.6-31

On Page 5-7, you calculate the volumetric flow rate, Q, using the equation: You state that this formula is for circular jets from "Section 3 above." Please clarify the origin of this equation, it is not clear to the staff where "Section 3 above" is. In addition, justify the use of this equation by justifying that the conditions in which it was derived are similar to those in which it is applied.

GE Response

The reference is to the earlier table (Table 9.3 from, Reference 1) for axisymmetric submerged jets. The value 4.26 is obtained for a circular jet of 3 mm diameter and at 4 cm from the jet initiation. The representation of the flow into the nosepiece by submerged jets of an equivalent diameter of 3 mm was discussed in the response to the previous RAI.

NRC RAI 21.6-32

On Page 5-7, you calculate that velocities on the order of 7 cm/s at the inlet to the fuel bundle should prevent any settling of boron into the lower plenum. This calculated value is based upon many different input parameters. Please evaluate the uncertainty of this value based upon the approximate values used for the lower tie plate opening as well as the pressure drop / hydraulic diameter of the nosepiece. What is the sensitivity to the assumptions about the geometry and flow characteristics at the interface between the bypass and the fuel support piece?

GE Response

It is estimated that the value of 7 cm/s for the critical velocity is conservative by an order of magnitude. First of all, there are numerous conservatisms in the estimation of the subcooling of 10 C in the plume at the bottom of the bypass. No credit is taken for any entrainment into three of the four plumes. Next, the 10 C subcooling is applied directly to the leakage flow as it enters the nosepiece. In reality, the flow has moved from the periphery of the bypass over a substantial region over the core support plate to get to the interior bundles, and will have very little subcooling left. Thirdly, application of the CCFL correlation to determine a bounding Froude number in a situation where the density differences are of the order of 2% and less is extremely conservative. These conservatisms are far greater than uncertainties in the application of the jet mixing model to the nosepiece.

A better estimate is being made with a CFD analysis of the nosepiece geometry.