NRC Staff Questions with Problem Statements

(Enclosure 6 to ML080510080 phone call summary of October 31, 2007 and November 29, 2007 phone calls with Alion)

Enclosure 6

Alion Follow-Up Issues (Updated 2/11/08)

Head Loss and Scaling

1. It is not clear to what extent the poured debris bed formation process can generate uniform/homogeneous debris beds. Previous unexpected test results from SONGS (where no measurable head loss was recorded, in contrast with NUREG/CR-6224 correlation predictions) and TMI (where the measured head loss across the VUEZ flat plate was significantly lower than the head loss measured across a 3x3 array) suggest that the debris bed formation process may not allow the flow through the screen to orient the accumulating debris in a natural arrangement that tends to maximize head loss. Discussion during a teleconference that additional fibrous debris is sometimes added to poured debris beds to fill in visually apparent gaps or non-uniformities further underlines the staff's concern that the porosity of a poured debris bed can be significantly higher than that of a bed that is naturally formed by flow. The small size of the VUEZ loop also implies that any non-uniformity in the test debris bed would tend to have a more significant effect than on a prototype module or plant strainer.

   Additional observations made during the staff's trip to VUEZ have reinforced previous observations above that the VUEZ poured beds are significantly more porous and fluffier than beds formed under flow. For example, several of the beds formed (with a quantity of debris more than sufficient to form a thin bed) unexpectedly resulted in essentially zero head loss, several appeared clumpy and non-uniform, and one even had a small amount of open screen area. The staff also visually observed issues associated with pouring the beds, such as disturbances to the bed from the funnel used to pour debris on the screen, clogging of the funnel with clumps of prepared debris, and the use of a stirring rod to reposition clumps of debris that had been poured onto the test screen non-uniformly. Virtually all of the comparisons the staff has observed to date between VUEZ testing and other test methodologies and analytical calculations have shown that the VUEZ head loss test results without chemical precipitates are non-prototypically low (and sometimes not significantly more than the clean screen head loss). The staff considers it likely that the bed pouring process is a significant factor causing these non-prototypical differences.

In light of the previous testing experience discussed above, Alion should demonstrate that head loss results from VUEZ testing with poured debris beds prior to the addition of chemicals are representative of non-chemical integrated tank testing head loss results (and/or other results from tests where the beds are formed under flow) after the results are scaled to a common temperature, as appropriate.

2. The specific methodology and technical basis for using a bump-up factor to account for the head loss due to chemical effects is not clear to the staff. The bump-up approach is based on the theory that the incremental head loss from a given quantity of chemical precipitate (after scaling) will be the same for the VUEZ debris bed as for the plant condition. One of the important assumptions upon which this theory depends is that the VUEZ debris bed and the actual plant debris bed should have sufficiently similar characteristics with respect to filtering out and spatially accumulating the chemical precipitates. Based upon testing conducted to date, it is not clear to the staff that geometric differences and other factors do not influence the debris bed's properties (e.g., porosity, compression, thickness), and thus add significant uncertainty to the bump-up factor approach. It is also not clear how the bump-up approach ensures that boreholes or differential-pressure effects do not adversely affect the scaling approach.

In light of the discussion above concerning geometric effects, debris bed properties that affect chemical precipitate filtration (e.g., porosity, compression, and thickness), and differential pressure effects, Alion should demonstrate that the incremental impact of chemical precipitates in VUEZ testing is representative of the incremental impact that would be expected for an actual plant.

3. During a series of pre-tests conducted prior to the staff's trip to VUEZ, sensitivity tests associated with the sequencing of debris into the test tank showed a significant difference in head loss associated with varying the arrival sequence of debris on the test screen for the same debris loading. In one case, the debris was added homogeneously, which resulted in a low head loss. However, in the heterogeneous case, the test was stopped prematurely after the head loss had rapidly increased to a value approximately 20 times greater than the homogeneous case. The staff questioned the basis for such a large discrepancy between these two cases and questioned why the homogeneous addition sequence is representative. Further, because the bump-up approach implicitly assumes similarity between the debris bed formed in the integrated tank to the bed formed in the VUEZ loop, it is not clear why the same debris addition sequence should not be used for both tests.

In light of the large sensitivity of measured head loss to the debris addition sequence discussed above, Alion should demonstrate (a) why the addition sequence for the VUEZ test debris is representative of the actual plant condition and (b) the basis for using a bump-up approach in light of the fact that a different debris addition sequence was used in the Warrenville array tests and the VUEZ tests.

4. During the initial teleconference, Alion stated that a generic fiber size distribution was used for the VUEZ testing. The staff expectation is that an appropriate procedure for preparing fine fiber be implemented (which is particularly important for the thin bed test, since for many plants, fines may be the only debris size that actually covers the entire strainer), and that the surrogate debris used matches the plant-specific size distributions from the debris transport calculation. The staff's observations at VUEZ showed that the prepared debris contained chunks that seemed to disrupt the formation of uniform debris beds. Further, since a fixed quantity of water was used to form all of the debris slurries, the cases with the highest debris loadings had the most concentrated and agglomerated debris slurries, which resulted in the formation of the most clumpy and non-uniform beds. Also, although a pre-test pour of the prepared debris over a perforated plate was used to determine whether the debris had been adequately fragmented after one of the tests for which a high concentration of chunks had clogged the funnel used to pour the debris onto the test screen, Alion did not generally perform a verification that the size distribution of the prepared debris was adequate prior to adding it to the test loop.

In light of the discussion above, Alion should (a) ensure that debris added to future tests is in a form that is representative of the plant debris described in the debris transport calculation and (b) demonstrate that testing conducted to date with a generic size distribution that led to significant debris clumping is adequately representative of the plant conditions predicted in the debris transport calculation.

5. Maximum load versus thin bed testing. During the previous call, Alion made the statement that maximum debris cases are chosen for chemical testing based on their causing higher head loss than the thin bed tests during earlier non-chemical testing. Presuming that the bump-up approach is justified, once chemicals are considered, the maximum debris case would continue to be bounding only as long as the thin-bed bump-up factor is not so severe as to overcome the lower thin-bed head loss without chemicals, or

$$\frac{Thin\ Bed\ Bump-up\ Factor}{Maximum\ Load\ Bump-up\ Factor} \leq \frac{Maximum\ Load\ HL}{Thin\ Bed\ HL}$$

In light of the discussion above, Alion should demonstrate that the head loss results from testing at VUEZ with the maximum debris load case would bound the head loss for the thin bed case for plants that are not testing a thin-bed condition.

6. During the most recent phone call, Alion stated that larger bump-up factors were calculated for maximum load cases as opposed to thin-bed cases based on previous VUEZ testing. Provided that these tests were not unduly influenced by issues such as debris coarseness and bed pouring, and that general principles can be deduced from these results that are applicable to other plants' test conditions, then it may be appropriate to use these tests as a basis to rule out the conduct of future thin bed tests. However, at present, based on unresolved staff concerns such as the debris-pouring process, debris size distribution, and debris sequencing, the staff does not consider omitting thin bed tests in the future to be justified. In addition, the procedure and technical basis for determining the appropriate thickness of the thin beds in the VUEZ tests was not fully clear to the staff during the phone call.

In light of the discussion above, Alion should (a) describe the basis for determining an appropriate thickness for thin beds being tested at VUEZ and (b) demonstrate that the thickness used for testing is bounding with regard to head loss.

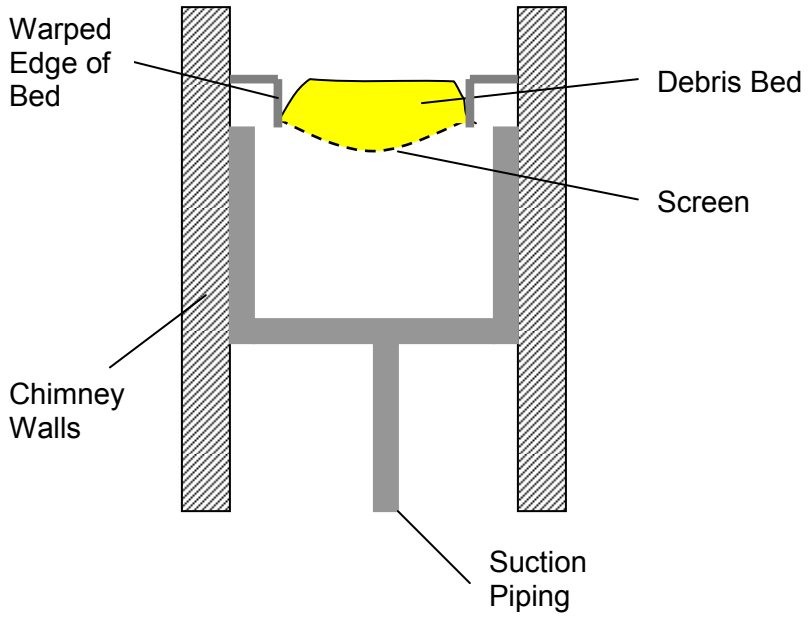
7. While the large VUEZ loop potentially offers a means of accounting for circumscribed and partially circumscribed (transitioning) debris beds, it is not clear whether the flat plate in the small loop can be scaled for these conditions (e.g., modeling effective bed thicknesses, circumscribed / partially circumscribed flow areas and approach velocities). As discussed in a previous teleconference, these geometric effects may be partially responsible for reduced head loss seen for TMI test conditions in the VUEZ loop as compared to the large tank with the 3x3 array.

In light of the discussion above, Alion should demonstrate that the methodology used to scale the results of VUEZ flat plate tests to a strainer array is adequate in the case of a circumscribed or partially circumscribed (transitioning) debris accumulation.

8. It is important to ensure gas release and boreholes do not disrupt the debris bed structure. Alion has stated that improvements have been made to address this issue for the small VUEZ loops, and that the limited experience to date has not shown there is a gas issue with the large VUEZ loop. Following the improvements to the small loops, observations made during the staff's trip to VUEZ showed that significant portions of two of the four beds formed floated away within several hours of formation. The buoyancy of parts of these beds may have been the result of gas evolution from the Temp-Mat binder; however, this explanation could not be verified during the staff's visit. Staff review of additional test results demonstrating that gas issues have been addressed could provide a basis to resolve the issue.

In light of the discussion above, Alion should demonstrate that gas issues have not had a significant adverse effect on the testing conducted at VUEZ.

9. In two tests that were completed during the staff's visit, inward warping of the upper surface of the debris bed away from the walls of the "chimney" was observed, as shown below in an idealized cross section (not to scale). Such warping of the debris bed could result in a significant amount of the flow passing through the thinner cross section of the debris bed nearest the chimney walls.



In light of the discussion above, Alion should (a) demonstrate that flow diversion through the thinner debris bed cross section caused by circumferential warping has not had a significant adverse impact on testing conducted at VUEZ and (b) describe measures taken to prevent or minimize this observed phenomenon in future testing.

10. During the staff's trip to VUEZ, corners of two tanks that had been run for several weeks contained small piles of debris, and a thin film was observed on the tank floor. This debris may be part of the material that was supposed to form the debris bed, material that leaked out of sample baskets, or settled chemical precipitates. Alion should understand the sources of any debris found on the floor of the tank, and, if significant settling of debris is observed, justify why the settling is acceptable. For tests where a large number of baskets of material and coupons have been added, additional areas of low flow may be created, thus further facilitating settling of debris. It is not clear that informal transportability tests performed in the past have accounted for the obstacles created by sample baskets and coupons, and, in addition, the staff noted that some of the testing observed during the trip had been conducted at tank flow rates that were lower than previously considered desirable (i.e., 1 L/min).

In light of the discussion above, Alion should (a) procedurally document the extent of debris settlement in the tank for each test and the justification for any observed settling being acceptable and (b) demonstrate that reduced flow rates and the addition of sample baskets and coupons does not cause non-prototypical settling in the test tank.

Chemical Effects

11. The NRC staff is interested in how a given licensee determines that the test parameters selected for the VUEZ loops provide test results that are conservative with respect to chemical effects. This is particularly important since test results may show that certain dissolved species remain in solution instead of forming precipitate in the time frame of interest. For example, as was described by Alion in a previous phone call, the early part of the test may be conducted with temperatures representative of the upper range of post-LOCA temperature profiles for a plant to favor dissolution of materials. The latter part of the test may be conducted at temperatures representative of the plant's lower temperature profile to favor precipitation of dissolved materials. With respect to test pH, higher pH conditions may favor greater dissolution of important materials, such as aluminum, while near neutral pH values would provide conditions that favor precipitation of aluminum hydroxide type species.

In light of the discussion above, Alion should demonstrate that the pH profile as a function of time is conservative for both material dissolution and precipitate formation.

12. Tests are initially conducted for an extended period at an intermediate temperature and low pH to account for the test equipment's inability to test at the short-term, peak post-accident temperatures. Alion considers the extended period at a lower temperature and lower pH to be conservative.

In light of the discussion above, Alion should demonstrate that it is acceptable to run the initial stages of a test at an intermediate temperature and low pH from the perspective of corroding aluminum and other materials.

13. The acids HCl and HNO3 are added early in the test sequence; however, in the actual accident scenario they will build in slowly over the mission time due to the degradation of cables and other sources. At a plant for which the primary precipitates are aluminum-based, the staff generally expects that a conservative test would attempt to produce an upper-bound pH early in the test sequence to maximize the corrosion of aluminum, and to produce a lower-bound pH later to encourage precipitation. Therefore, why is it acceptable to add all of these acids generated in a 30-day period in an addition during the early stages of the 30-day test?

In light of the discussion above, Alion should demonstrate that it is acceptable to add the hydrochloric and nitric acids at the early stages of the test rather than later in the event when they are postulated to actually form.

14. For the tests observed by the staff, the majority of the LiOH was added with the buffer, with only a small portion (one tenth of total) being added with the boric acid. At VUEZ, the buffer and larger portion of LiOH are added over a period spanning several hours after boric acid injection in the tank; however, in an accident scenario at a plant, the LiOH would be present from the onset of the event. Why is the delayed injection of LiOH acceptable? Would the presence of the LiOH early in the test allow for a higher starting pH and therefore increased corrosion of materials such as aluminum?

In light of the discussion above, Alion should (a) describe the impact of adding LiOH with the buffer rather than having it present at the onset of a test and (b) demonstrate that the delayed injection of LiOH is acceptable.

15. In several of the tests observed by the staff, the debris bed materials (Nukon, TempMat, calcium silicate, surrogate dirt, etc.) were allowed to sit in the baby loops for roughly eight to 10 hours prior to other materials and chemicals being added. This resulted in the de-ionized water climbing in pH from 7 to 9.6 prior to addition of other materials. This phenomenon would not exist in an actual accident scenario because of the boric acid and buffer in the pool. What is the impact of this initially high pH? Does it create a more conservative or less conservative scenario when considering dissolution of materials early in the test sequence and precipitation of materials later in the test? In addition, has benchmarking been done to discern whether similar amounts of materials that have been packed into sample baskets can result in similar impacts on the pH?

In light of the discussion above, Alion should (a) describe the impact of elevated pH due to debris dissolution in demineralized water and (b) demonstrate that pH changes associated with debris dissolution in demineralized water do not have a significant adverse impact on the test results.

16. The existing VUEZ testing does not address the effect of a sudden temperature drop from a heat exchanger and the potential for thermal cycling. During the teleconference, Alion stated that equipment was being procured to analyze this effect. Additional detail on how these tests will be conducted and their results could provide a basis to resolve the issue.

In light of the discussion above, Alion should (a) describe the impact of thermal cycling of the test fluid to represent a sudden temperature drop in a heat exchanger and (b) demonstrate that neglecting this effect does not have a significant adverse impact on the VUEZ test results.

17. Zinc and aluminum coatings are being represented by increasing the surface area of zinc and aluminum coupons. Is the corrosion of aluminum and zinc coupons representative of the dissolution of significantly smaller chips or particles of failed coatings debris (e.g., in terms of surface-area-to-volume ratio)?

In light of the discussion above, Alion should demonstrate that it is acceptable to model the corrosion of metallic coatings (e.g., zinc and aluminum) based on their mass or volume rather than by their exposed surface area.

18. As discussed during the recent phone call, the rapid addition of buffer to the VUEZ test loop has been shown to cause a temporary increase in head loss.

Alion should identify the cause of the head loss increase that was associated with the rapid addition of buffer material in some of the early VUEZ tests.

19. The protocol for the tests observed at VUEZ was to boil the Temp-Mat and Nukon fibers to drive off the binder material prior adding the fiber to the tanks. In a similar fashion, some of the Temp-Mat material was baked to help drive off any binder material. The staff agrees that in a traditional head loss test (one not considering chemical contribution from the test materials) it may be preferable to prepare the fibers in this way because it simulates the interaction of the fibers with hot surfaces during service and the hot reactor fluid after an

accident. However, in an actual accident scenario some binder material could be present in the sump pool and could potentially contribute to chemical effects. In contrast, at VUEZ, the water used to boil the fibrous debris is drained off and never added to the test tank. Why is it acceptable to not include the binder material in the test tank? What is the composition of this material and what is the potential impact on chemical effects?

In light of the discussion above, Alion should (a) describe the impact of neglecting the binder of heat-treated fibrous insulation and (b) demonstrate that that neglecting the binder does not have a significant adverse impact on the test results.

20. For the tests observed by the staff, care was taken to thoroughly mix the tank fluid (by mechanical mixing) after the addition of the boric acid. This was done because, as VUEZ personnel indicated, it can take longer than 4 hours for complete mixing of the test tank fluid. This same procedure is not used when the buffer, the HCl, the HNO3, and the last portion of LiOH are added later in the test. This is due in part to the inability to get a mechanical mixer in the tank due to physical limitations caused by the volume taken up by coupons and baskets of material in the tank at the time of those additions. The mixing of these chemicals into the bulk fluid will take even longer due to the complex geometries and uneven flow zones created by the coupons and baskets. The reason that this is a potential concern to the staff is that the timed removal of coupons and baskets is based on the time allowed to interact with these chemicals. If the chemicals are not well mixed then the coupons and baskets may not be getting the chemical interaction they are assumed to get prior to removal. As an example: An aluminum coupon is placed in the tank at time zero. The chemicals are then added and the time of interaction of that coupon, as modeled based on the time of exposure to containment spray, begins. After 4 hours of interaction the coupon is removed. However if the chemicals, or the coupon/basket, were isolated in a low flow / unmixed zone of the tank, the actual time of interaction may be far less.

In light of the discussion above, Alion should demonstrate that, for coupons and debris baskets that are only in the test tank for a discrete period of time, the potential for slow or non-uniform mixing of the test fluid and the potential for unevenly mixed chemical constituents does not have a non-conservative impact on the corrosion/degradation of the coupons and debris baskets, which are assumed to be in contact with well-mixed test fluid for the entire period of immersion.

21. The staff had several questions concerning the modeling of the interaction of the test fluid with the debris samples and coupons in the test tanks. Many of the debris sample baskets used for the testing are shaped like a tray, allowing for fluid interaction with the material in the basket only through one open “screened” surface. Thus, due to the geometry of the sample baskets, there is only minimal flow of water past the samples, which reduces the ability of the test fluid to interact with the sample materials. This problem is compounded when the baskets are densely packed with debris, which the staff observed for several tests with large debris quantities, including cases where one material was densely packed on top of a second material inside the basket, providing this material a shielding effect from the test fluid. In addition, several of the tests observed by the staff required large quantities of debris that filled a significant fraction of the available test tank volume. Stacked or closely spaced baskets have the potential to limit further the interaction of the test fluid with the sample materials in the baskets. In addition, the staff observed in one test that a sample coupon was inserted in the test tank with one side very close or adjacent to the wall of the test tank, which appeared to prevent significant flow of the test fluid to approximately half of the coupon surface area. All of these issues are tied to the staff’s larger concern that the sample materials added to the test tank may not be able to interact with the test fluid in a

representative manner. As a result, fewer chemical species could be dissolved into the test fluid, and therefore there may be a non-representative reduction in the potential for formation of chemical precipitates in the VUEZ test loop.

In light of the staff observations of debris densely packed into baskets, debris baskets with only one open side, and debris baskets and samples being tightly spaced in the test tank, Alion should demonstrate that the test tank fluid at VUEZ can interact with the materials in the tank in a representative manner.

22. In the tests observed by the staff, several liters of test fluid had to be physically removed in order to add all of the debris and buffering chemicals. This removal results in the fluid volume of the test tank being reduced and the concentrations of the chemicals in the loop being varied from the test specification.

Alion should demonstrate that the volume reduction caused by the removal of fluid during testing to make room for debris samples does not have a significant adverse impact on the concentration of dissolved chemical species in the test tank.

23. Removal of materials from the test tank: (1) By the end of the test, based on the procedures provided, approximately five percent of the loop volume could be removed through the process of sampling the test volume (including any dissolved and suspended species). (2) Small quantities of particulate that are considered non-transportable are not included in the test for their chemical impacts (e.g., ALION-CAL-SONGS-4194-03, Rev. 2, Pg 29 of 35). How much of these materials may be removed without significantly affecting the test results?

Alion should demonstrate that removing fluid during testing does not have a significant adverse impact on the test results through the removal of dissolved chemical species, particulate, or other fine debris.

<u>Test Procedure / Miscellaneous</u>

24. Confidence should exist that the VUEZ tests are repeatable. Alion discussed TMI testing that is currently underway and stated that it has shown some evidence of repeatability thusfar. The staff expects that data for slightly varied test conditions should also be capable of providing evidence of repeatability if it correlates with expected behavior.

    However, based upon the staff's observations from the trip to VUEZ, evidence for the repeatability of the debris bed formation process was not conclusive. Although some of the tests appeared to demonstrate repeatability, other tests demonstrated significant variability. Among the tests observed by the staff included two pre-test cases, four test cases, and two repeat test cases that became necessary when significant portions of two debris beds floated away.

In light of the discussion above, Alion should demonstrate that the results of the VUEZ testing are repeatable to within an acceptable tolerance.

25. How are measurement uncertainties accounted for / propagated through the analysis? Between the flow rate measurement, flow control, head loss measurement, and temperature measurement, there could be a relatively high uncertainty associated with the head loss results. (Variances of independent random variables are additive.) In addition, uncertainties associated with temperature could affect the timing of the corrosion process – for example,

Alion approximated in its test procedure that corrosion rates double about every 18°F – and, thus, the timing of precipitate induced head loss.

In light of the discussion above, Alion should demonstrate that neglecting measurement uncertainties associated with the VUEZ testing does not have a significant adverse impact on the validity of the test results.

26. The staff requests a copy of the test procedure for the large VUEZ loop and is interested in any experience from this loop with regard to debris bed formation and other issues discussed above regarding the small loops, such as a comparison of head loss results to prototype testing, settling, and circumscribed scaling. Based on the staff's observations of a pre-test conducted for one plant in the large loop, a number of the issues described above may similarly apply to testing in the large loop.

Alion should (a) provide the staff a copy of the test procedure of the large VUEZ loop and (b) ensure that any actions taken to address staff concerns on small loop testing are also taken with regard to the large loop testing protocol, as applicable.

27. What is the schedule for providing a copy of the report on the deterioration of alkyd coatings in post-LOCA containment pool to the NRC?

Alion should provide the NRC staff a copy of the report on the deterioration of alkyd coatings in a post-LOCA containment pool.

28. The staff noted several quality assurance issues associated with the testing. During one of the tests that was nearly completed the staff observed a sample material basket that had been resting screen-side down (presumably for the duration of the test), such that no basket surfaces were open for fluid interaction with the test fluid. As a result, no leached material from the debris samples in this sample basket could have participated in the test. During tests for a different plant, the procedure required that boiled Temp-Mat be added to the tank; however, the Temp-Mat that was added to the tank did not appear to the staff to have been boiled. After significant parts of two of the four formed debris beds floated away, the vendor then stated that it was not clear that the Temp-Mat had been boiled and attributed the partial floatation of the two debris beds to the Temp-Mat not having been boiled. Why is there confidence that these sorts of quality assurance issues have not occurred during previous tests and will not occur again in future tests?

In light of the issues identified above, Alion should demonstrate that the quality assurance associated with the VUEZ testing is adequate.

29. Very few photographs were taken by the vendor during the staff's visit. The staff considered it beneficial for Alion to consider documenting key steps in the test procedure (e.g., the prepared debris, the process of adding debris to the test tank, the quantity of settled debris in the tank, the formed debris bed, the removed debris bed and sample coupons, etc.) with photographs and/or video, because such tools provide a valuable record of how a head loss test was conducted.

Alion should consider using additional photographs and video of key stages of the VUEZ testing to provide a record that can demonstrate whether tests were conducted in a representative manner.