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January 9, 2018

Docket Nos.: 50-424
50-425

NL-17-2045

U. S. Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington, D. C. 20555-0001

Vogtle Electric Generating Plant- Units 1&2
Systematic Risk-Informed Assessment of Debris Technical Report SNC Response to NRC Request for Additional Information (RAIs #11-14)

Ladies and Gentlemen:

By letter dated April 21, 2017 (Agencywide Documents Access and Management System Accession No. ML17116A098) as supplemented by letter dated July 11, 2017 (ADAMS Accession No. ML17192A245), Southern Nuclear Operating Company, Inc. (SNC) submitted a plant-specific technical report for Vogtle Electric Generating Plant (VEGP), Units 1 and 2 and requested U.S. Nuclear Regulatory Commission (NRC) approval of the methods and inputs described in the technical report. The plant-specific technical report describes a risk-informed methodology to evaluate debris effects with the exception of in-vessel fiber limits.

By letter dated November 22, 2017, the NRC staff notified SNC that additional information is needed for the staff to complete their review. On December 12 and 13, 2017, NRC staff conducted an onsite audit for the review of the VEGP Seismic Probabilistic Risk Assessment (SPRA) model for use in the approved SNC 10 CFR 50.69 program. During the onsite visit, SPRA Request for Additional Information (RAI) #15, for this application, was also discussed. As a result of those discussions, the NRC notified SNC staff that RAI #15 has been revised and the revision was provided, in draft form, to SNC staff by email dated January 3, 2018. The Enclosure provides the SNC response to the NRC requests for additional information for RAIs 11-14. The SNC response to RAI 15 will be provided in a later submittal.

This letter contains no NRC commitments. If you have any questions, please contact Ken McElroy at 205.992.7369.

I declare under penalty of perjury that the foregoing is true and correct. Executed on the 9th day of January 2018.

Respectfully submitted,

SOUTHERN NUCLEAR OPERATING COMPANY

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Enclosure: SNC Response to NRC Request for Additional Information (RAIs)

cc: Regional Administrator, Region II
NRR Project Manager – Vogtle 1 & 2
Senior Resident Inspector – Vogtle 1 & 2
State of Georgia Environmental Protection Division
RType: CVC700

<u>Vogtle Electric Generating Plant Unit 1 and 2</u>

Enclosure

SNC Response to NRC Request for Additional Information (RAIs)

NRC RAI 11

It is stated in Enclosure 1, Section 7.0, "Quality Assurance" (QA) that:

> ... most of the analysis and testing for the risk-informed Generic Safety Issue (GSI)-191 evaluation was performed as safety related under vendor QA programs compliant with Title 10 of the Code of Federal Regulations (10 CFR) Part 50 Appendix B.

While this section describes exceptions regarding specific equations within the NARWHAL software, explicit discussion of quality assurance measures associated with the software development was not included.

a. Please describe quality assurance procedures taken (e.g., validation and verification processes) to ensure the NARWHAL software produces high fidelity results.

b. Please describe tests of BADGER software performed to verify that the total debris monotonically increases with break size.

SNC Response to RAI 11 Part a

The NARWHAL software was developed by ENERCON under their 10 CFR Part 50 Appendix B QA program. The status, adequacy, and effectiveness of ENERCON's QA program is regularly assessed by internal audits and audits conducted by external stakeholders. ENERCON successfully passed a joint nuclear utility audit conducted under the auspices of NUPIC in June 2016. The NUPIC audit scope included ENERCON's software development processes and resulted in ENERCON being added by NUPIC as an approved supplier of safety-related software.

NARWHAL was developed as a safety related item with rigorous documentation including the following technical and administrative documents:

- Software quality assurance plan (SQAP)
- Software requirements specification (SRS)
- Software configuration management plan (SCMP)
- Software verification and validation plan (SVVP)
- Software architecture document (SAD)
- Software design and implementation document (SDID)
- Software verification and validation (V&V) report (SVVR)
- Software user's manual (SUM)
- Project instruction for preparing, packaging, and delivering NARWHAL software

The software V&V is accomplished by a) rigorously identifying all software requirements in the SRS, b) identifying which of these requirements should be quantitatively tested in the SVVP, and c) performing the required tests and documenting the results in the SVVR. Due to the complexity of the software, ENERCON performed two separate V&V exercises:

- A developer V&V where personnel directly involved in the software development created a suite of tests
- An independent V&V where personnel independent of the development process created a separate suite of tests

The process for developer and independent testing proved to be very effective for identifying and correcting errors prior to releasing the software for use. For new versions of NARWHAL, new tests are added to test the new functionality, and regression testing is performed by rerunning the previous suites of tests to ensure that the code modifications did not cause any previously working code to fail.

The ENERCON QA program provides a process for users to identify software anomalies and for developers to subsequently determine whether an anomaly is a software error. Software errors are classified as major or minor based on whether they substantially affect calculated results. For each error, an error notice is issued to the software users and a corrective action report (CAR) is initiated in the ENERCON corrective action program to ensure that the appropriate corrective actions are taken (including Part 21 notifications as necessary).

To date, only a few minor software errors have been identified in released versions of NARWHAL. All identified software errors have been corrected in the latest software release (NARWHAL Version 3.0). The corrective actions included steps taken to address issues that allowed these errors to slip through the V&V process and the addition of new V&V tests that would have caught these errors.

Three of the minor errors affected NARWHAL Version 2.1, which was the version used for the Vogtle GL 2004-02 supplemental response (Ref. 1). Two of the errors were identified prior to issuing the supplemental response, and had no effect on the Vogtle results. The third error was identified after issuing the supplemental response. This error had a slight effect on the transported fire barrier particulate and fire barrier fine fiber debris quantities shown in Enclosure 2 of the supplemental response (Tables 3.e.6-15). However, the error had no effect on the overall conditional failure probabilities.

Note that Vogtle has recently updated the NARWHAL calculations with the following changes to the Vogtle model:

- Upgraded the model from Version 2.1 to Version 3.0
  - Corrects three minor software errors (see above) resulting in minor changes for the transported fire barrier debris quantities and strainer head losses.
  - Provides additional options for analyzing degasification and flashing.
  - Allows more efficient post-processing of results using the NARWHAL GUI.
- The reference elevation for flashing (set at the top of the strainer) was separated from the reference elevation for degasification (set at the mid-point of the strainer).
- Containment accident pressure was defined as 3.5 psi and was only credited for the first 2.5 hours of the event (for both degasification and flashing calculations) rather than the entire event.
- The reactor vessel flow split was modified to more realistically model simultaneous injection during hot leg recirculation with the residual heat removal and safety injection pumps injecting into the hot legs and the charging pumps continuing to inject into the cold legs.

- The coatings debris quantities were compared to head loss tested limits on a volume basis rather than a mass basis.
- Credit was taken for the location of unqualified coatings (i.e., the quantity in upper containment versus lower containment).

The net effect of these model changes made no difference in the overall results for the base case (i.e., the breaks that passed and failed and the resulting conditional failure probabilities were identical).

SNC Response to RAI 11 Part b

The BADGER software, which was developed by ENERCON, is used to create, position, and size the zone of influence (ZOI) spheres or hemispheres for double ended guillotine breaks (DEGBs) and partial breaks. It is also used to calculate the quantity of insulation or coatings debris within a given ZOI and the centroid distance for use in size distribution calculations. BADGER performs these functions by manipulating the Autodesk Inventor software using Inventor's application programing interface (API). Therefore, validating the results is done in two steps.

The first step is to validate the results of the Inventor calculations. ENERCON has completed this by performing a commercial grade dedication (CGD) of the Inventor software in accordance with their 10 CFR Part 50 Appendix B QA program. The CGD identifies the critical characteristics of the Inventor software (which includes volume, area, and length calculations) and tests these characteristics to ensure that results are accurate. The tests are performed using relatively complex geometry with comparisons to hand calculations. For the purpose of GSI-191 evaluations, the acceptance criteria were that the Inventor calculations should be accurate within 5%, although the comparisons to hand calculations showed accuracy within less than 1%.

The second step in the validation process is to ensure that the Inventor manipulations performed by BADGER (including calculating ZOI debris quantities and centroid distances) are performed correctly. This was also accomplished in accordance with ENERCON's 10 CFR Part 50 Appendix B QA program in the BADGER SVVR, which included several V&V tests for various insulation configurations and ZOIs. These V&V tests were focused on the results of individual configurations and break sizes, and did not include tests to verify that the total debris monotonically increases with break size.

When the BADGER results database for Vogtle was evaluated in more detail, it was discovered that in some cases the debris quantity does not always monotonically increase with break size (see example in Figure 11-1).

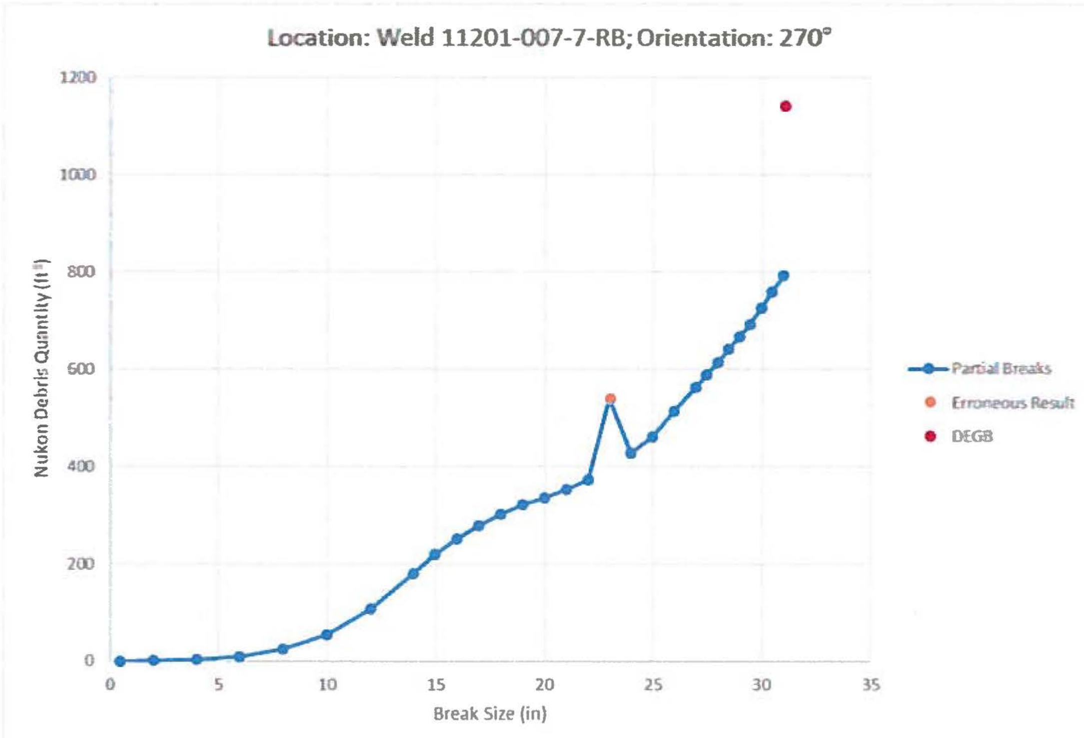

Figure 11-1: Example of weld that does not monotonically increase with break size

For a given break location and break orientation, it is not physically possible for a larger break to have a smaller debris quantity. Therefore, this is an erroneous result in the calculation.
A total of 28,434 breaks were analyzed (inside and outside the first isolation valve) in the Vogtle debris generation calculation. For each of these breaks, four separate ZOIs were evaluated to calculate debris quantities for Nukon, fire barrier, qualified coatings on concrete, and qualified coatings on steel. This gives a total of 113,736 ZOIs analyzed. The data was queried to determine the number of instances where a larger break generated a smaller quantity of debris for a given location, orientation, and debris type. The majority of the cases returned by this query showed an insignificant difference in debris quantities between break sizes. This can occur where, for example, a smaller ZOI encompasses the same insulation as a larger ZOI and Inventor calculated essentially the same value (within rounding error). For these cases, the results are acceptably accurate. To further refine the query, the results were filtered to show only the cases where a potentially significant erroneous result exists (a difference larger than 1% and 1 ft^3 or 1 lb_m). This yielded a total of only 47 ZOIs or 0.04% of all of the ZOIs analyzed. Of these 47 ZOIs, 25 were in the conservative direction and the other 22 were in the non-conservative direction.

In certain circumstances, Inventor is unable to compute the interference between two objects. This occurs when the outer surface of the ZOI is very close to the outer surface of the insulation resulting in thin interference features with very high aspect ratios. The potentially significant differences such as the example shown Figure 11-1 are likely due to similar issues with high aspect ratios under very specific conditions.

The potentially significant erroneous results for the 47 ZOIs were corrected in a modified BADGER database by conservatively using the debris quantity for the next larger break size at

the same location and orientation. A sensitivity case was run in NARWHAL, which showed that the variations for these debris quantities had no effect on the conditional failure probabilities.

In summary, although the cases where the debris quantity does not monotonically increase with break size are not physically realistic, they are relatively rare and can be readily identified with a systematic evaluation of the results. Also, a conservative correction of these cases has no effect on the conditional failure probabilities or the corresponding ΔCDF and ΔLERF values. Therefore, the results and conclusions presented in the Vogtle submittal are not affected.

NRC RAI 12

Enclosure 3, Section 13.1, "NARWHAL Software," states that the plant, at any given time, can be defined by a state vector (i.e., collection of parameters). A series of marching algorithms, constituting the core framework of NARWHAL software, are used to update the state vector by determining the amount of change in each variable given a change in time. While the submittal describes certain assumptions regarding parameters over times (e.g., instantaneous, 7.5 hours, etc.), the computer time step associated with the marching algorithms is not stated, nor is the dependence of the results on computer time-stepping.

Please describe the time step(s) used in executing the marching algorithms and whether those time steps are sufficient to ensure convergence of the results to capture the pertinent GSI-191 phenomena modeled properly (e.g., time evolution of head loss and in-core fiber penetration).

SNC Response to RAI 12

Each break evaluated in NARWHAL was run for a duration of 30 days (43,200 hours). The first 24 hours (1,440 minutes) were evaluated with a time step size of 1 minute. After the first day, the time step is increased to 60 minutes. This is a reasonable application since the majority of the transient occurs within the first few hours and long-term effects can be effectively analyzed with a coarser time-step.

The smallest time increment that can be specified in NARWHAL is 1 minute. However, each of the GSI-191 physical models that are implemented in NARWHAL have been compared against external calculations performed using spreadsheets, which do not have a limit on minimum time-step size. The most important time-dependent phenomena in the NARWHAL calculations are the chemical release/precipitation and the overall debris mass balance (including accumulation at the strainers, penetration through the strainers, and accumulation at the core). These models, and especially the mass balance calculations, have been extensively tested as part of the NARWHAL V&V. In addition, safety-related hand calculations have been developed for Vogtle for both chemical effects (including release and precipitation of each type of precipitate) and in-vessel effects (including fiber mass balance and strainer penetration).

Note that the rule-based approach used to calculate head loss (Reference 1, p. E5-82) results in simple step changes for the head loss values in NARWHAL. These head loss values are unaffected by the numerical integration parameters (i.e., time-step size). However, the quantity of fiber, sodium aluminum silicate (SAS), and calcium phosphate on the strainer were used to determine which head loss value is applicable. Therefore, these debris parameters were explicitly investigated using time-step sensitivity cases. The overall ΔCDF was also calculated for time-step sensitivity cases to show any effect when all pertinent GSI-191 phenomena are integrated in a single model. These sensitivity cases are described in more detail below.

The in-vessel effects calculation included a time-step sensitivity analysis that varied the time-step size for the first hour from 60 seconds (equivalent to the time-step size used in NARWHAL) down to 5 seconds for a given debris load, flow conditions, etc. The results of this analysis are shown in Table 12-1. A comparison between the 60 second time-step results and 5 second time-step results shows that the quantity that accumulates on the core inlet for a cold leg break (CLB) is reduced by approximately 19% and the total quantity that accumulates in the reactor vessel for a hot leg break (HLB) is reduced by approximately 5% when a smaller time-step size is used.

Table 12-1: Time Step Sensitivity on CLB and HLB Results

Time Step (secs)	CLB Core Inlet Load at HLSO (g/FA)	HLB Total RV Fiber Load (g/FA)
60	9.64	89.74
20	8.29	86.35
10	7.96	85.51
5	7.81	85.10

This indicates that there is some effect on penetrated fiber mass and core fiber accumulation as a function of the time-step size. However, using a larger time-step size is conservative with respect to the core failure criteria. Note that the uncertainty quantification documented in Enclosure 3 Section 14.2.3 of the submittal considered the bounding condition for strainer failure with 0% penetration (Ref. 1 pp. E3-70 to E3-72).

The safety-related hand calculation for chemical effects used variable time-step sizes to capture the available Vogtle thermal-hydraulic data as closely as possible with time steps less than half a second early in the event and less than 30 seconds for the first 4 hours. The maximum quantity of calcium phosphate was calculated to be 63.2 kg (139 lb_m) and the maximum quantity of SAS was calculated to be 40.2 kg (89 lb_m) in the hand calculation.

In the NARWHAL calculation, the maximum quantity of calcium phosphate calculated for the base case conditions was 116 lb_m (17% less than the hand calculation) and the maximum quantity of SAS was calculated to be 87 lb_m (2% less than the hand calculation). Note that in addition to the difference in time-step size, the hand calculation is based on a constant, maximum water volume. However, NARWHAL calculates a time-dependent sump pool volume, and for the base case calculation, this volume is based on minimum injection volumes and maximum holdup volumes. The hand calculation also included a case with a much lower water volume. As shown in Table 12-2, the variability between the NARWHAL results and the hand calculation is essentially directly proportional to the change in water volume, which is a key variable for chemical effects. This comparison indicates that the time-step size used in NARWHAL is sufficiently accurate.

Table 12-2: Time Step Sensitivity on Chemical Precipitate Quantities

Case	Total Water (lb_m)	Calcium Phosphate (lb_m)	Sodium Aluminum Silicate (lb_m)
Hand calculation – Maximum Precipitate Case	6,675,858	139	89
NARWHAL – Base Case	5,485,739	116	87
Hand calculation – Sensitivity Case	3,597,241	79	79

In addition to these comparisons with hand calculations, a series of sensitivity cases were run in NARWHAL using progressively larger time-step sizes. A total of six different time-step sizes were evaluated: 1 minute, 2 minutes, 3 minutes, 4 minutes, 5 minutes, and 15 minutes. After 24 hours (1,440 minutes), the time-step size remained at 60 minutes for each sensitivity (i.e., the time step size was only changed for the first 24 hours, during the transient portion of the analysis). As shown in Table 12-3, there is some minor variation in the overall results as a function of the time-step size. However, this variation is insignificant for time steps smaller than 5 minutes.

Table 12-3: NARWHAL Time-Step Sensitivity ΔCDF Results

Time step size	ΔCDF
Base Case (1 minute)	2.47E-08
2 minutes	2.48E-08
3 minutes	2.45E-08
4 minutes	2.49E-08
5 minutes	2.41E-08
15 minutes	4.47E-08

The following figures show the results from the equipment configuration with all pumps running for the break that results in the most fiber on the RHR strainer (DEGB at weld 11201-004-6-RB on the hot leg in Loop 4). Figure 12-1 and Figure 12-2 show the fiber accumulation on the RHR and CS strainers. As shown, the results have very little variability for the smaller time-step sizes, but are significantly different for the 15-minute time-step size.

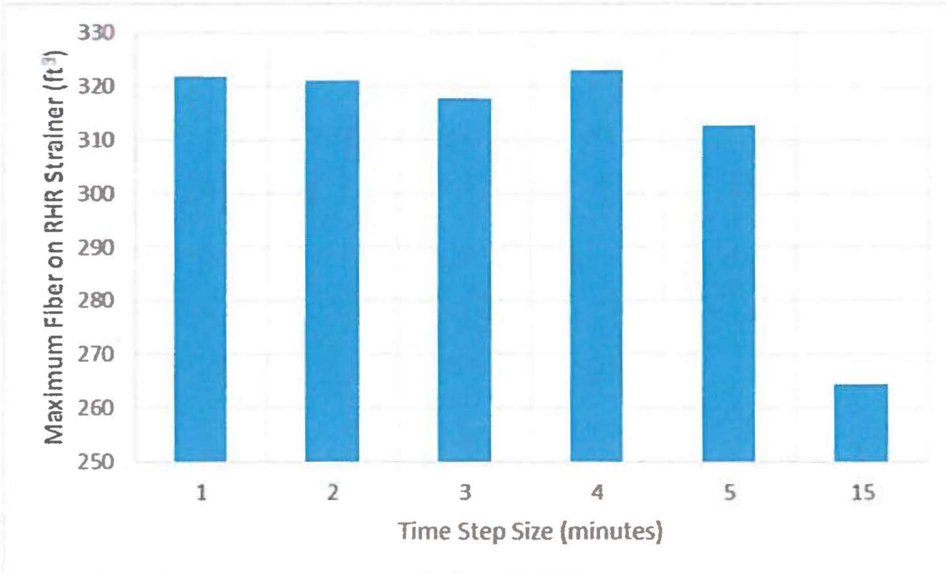

Figure 12-1: Maximum fiber on the RHR Strainer

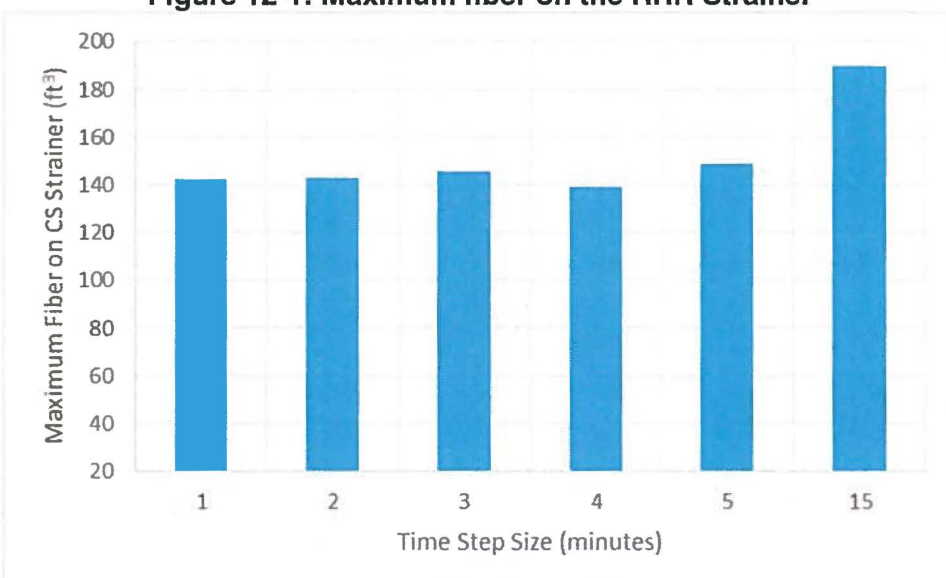

Figure 12-2: Maximum fiber on the CS Strainer

Figure 12-3 shows the maximum quantity of fiber in the reactor vessel as a function of time-step size. There is a definitive trend in this figure, where larger time-step sizes result in more fiber accumulation in the reactor vessel. This indicates that the penetration/shedding models are more sensitive to larger time-step sizes, which is consistent with the hand calculation sensitivity results discussed previously.

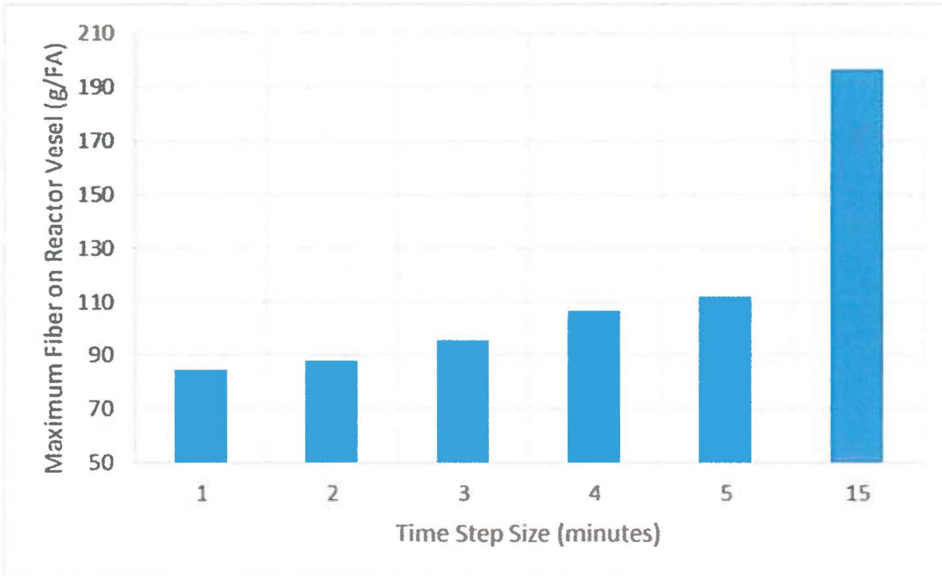

Figure 12-3: Maximum Fiber in the Reactor Vessel

Figure 12-4 and Figure 12-5 show the sodium aluminum silicate and calcium phosphate on the RHR strainer as a function of time-step size. As shown, the aluminum has a decreasing trend with increasing time-step size, and the calcium has an opposite trend.

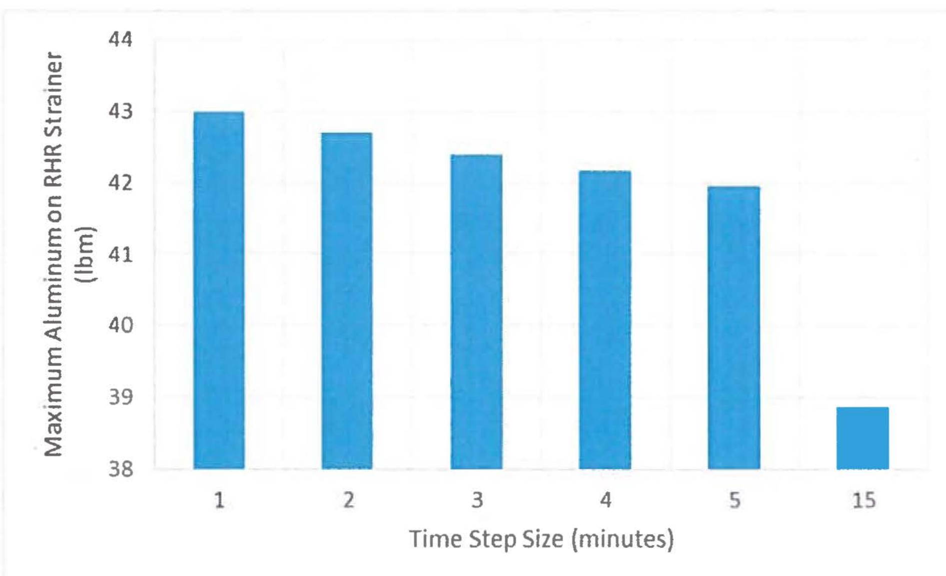

Figure 12-4: Maximum SAS on RHR Strainer

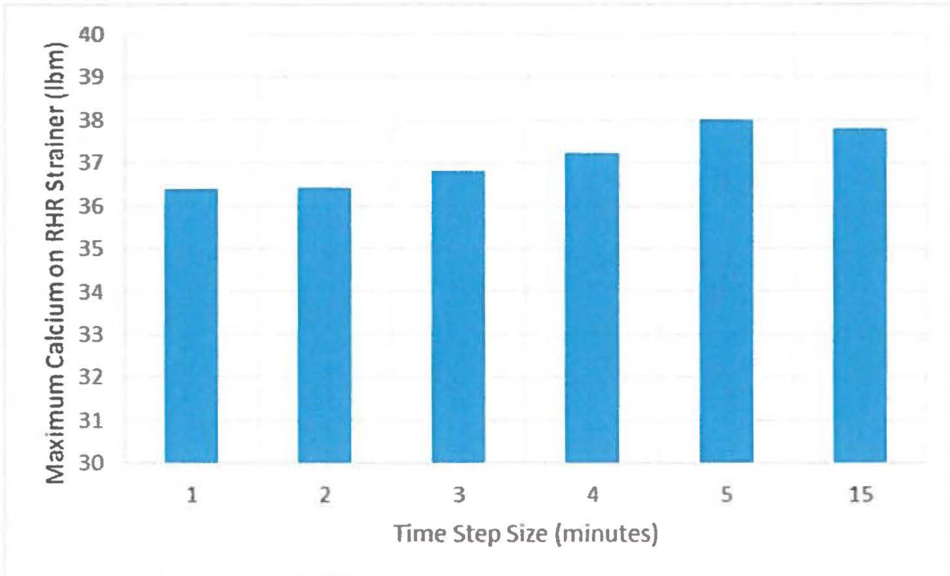

Figure 12-5: Maximum Calcium Phosphate on RHR Strainer

The overall conclusion from the NARWHAL sensitivities (with larger time-step sizes) and comparisons to hand calculations (with smaller time-step sizes) is that a one-minute time-step size for the first 24 hours is small enough to sufficiently capture the transient GSI-191 phenomena and accurately quantify the risk associated with GSI-191.

NRC RAI 13

Table 3-5 of Enclosure 3, Section 14.1, "VEGP NARWHAL CFP Evaluation," provides NARWHAL software conditional failure probability (CFP) values for Strainer A and B, Strainer A only, and Strainer B only. Given that asymmetric transport may actually occur, but is not modeled in NARWHAL (page E2-51, Enclosure 5) demonstrate that NARWHAL calculations of CFP yield conservative values of (or have a negligible impact on) delta Core Damage Frequency (CDF) (i.e., ΔCDF) and Large Early Release Frequency (LERF).

SNC Response to RAI 13

It is expected that transport to the two residual heat removal (RHR) strainers would be asymmetric due to the somewhat different flow conditions in the vicinity of the two strainers. However, assuming symmetric transport to both strainers is conservative because it maximizes the potential for both strainers to fail. With asymmetric transport, it is *more* likely for one strainer to fail, but *less* likely for the other strainer to fail. In other words, the NARWHAL model over-predicts failure of both RHR trains and under-predicts failure of a single RHR train. The reason this is conservative is because the PRA success criteria only requires operation of a single RHR pump for large breaks, and reducing the likelihood of both RHR strainers failing due to the effects of debris will decrease the core damage frequency (CDF).

The NARWHAL evaluation provides conditional failure probabilities (CFPs) that are conditioned on specific equipment configurations (e.g., all pumps running or single train failure). These equipment configurations are based on random (non-GSI-191 related) failures of the equipment. The effects of random pump failures (e.g., failure of a pump to start or failure to run) are

conservatively addressed in the NARWHAL model by assuming that the failures occur at the start of recirculation. As described in Enclosure 3 Section 13.2 Assumption 15 of the VEGP submittal, this assumption maximizes accumulation of debris on the active strainers and increases the CFP values associated with those equipment configurations (Ref. 1 pp. E3-36 to E3-37).

Changing the model to assume asymmetric transport and/or random equipment failures later in the event would reduce the conservatism in the model and result in lower CDF values.

NRC RAI 14

It is described in Enclosure 3, Section 14.2, "NARWHAL Uncertainty and Sensitivity," that competing factors affecting delta CDF (i.e., ΔCDF), as summarized in the tornado diagram in Figure 3-9 and in Tables 3-13 and 3-14.

Please explain the competing physical processes that determine the "bounding direction" for the following entries:

- Tables 3-13 - pool volume, pool temperature, secure containment spray time, pH.
- Table 3-14 - pool volume, pool temperature, emergency core cooling system flow rate, pH.

SNC Response to RAI 14

Table 3-13 and Table 3-14 in Enclosure 3 of the submittal provide a summary of the worst-case conditions for strainer failure and core failure, respectively (Ref. 1 pp. E3-67 to E3-70). The parameters that have competing effects on strainer failures are pool volume/level, pool temperature, the time that containment sprays are secured, and pH. The parameters that have competing effects on core failures are pool volume/level, pool temperature, emergency core cooling system (ECCS) flow rate, and pH.

The explanations for these competing parameters are described below:

- Pool volume/level affects several aspects of the GSI-191 evaluation including time-dependent transport, net positive suction head (NPSH) margin, degasification, flashing, the potential for a partially submerged strainer, chemical release, and chemical solubility. For most of these calculated parameters (NPSH margin, degasification, flashing, and partial submergence), a lower pool volume/level is more conservative. However, as described in WCAP-16530-NP-A, there are some competing effects where either a minimum or maximum pool volume could result in the most limiting chemical precipitate debris load (Ref. 2 p. 129). In addition, although early transport of debris to the residual heat removal (RHR) strainers is generally conservative, there are some competing effects with respect to fiber penetration. Specifically, if a filtering debris bed forms more rapidly on the strainers, it can lead to lower penetration fractions.
- Pool temperature also affects several aspects of the GSI-191 evaluation including NPSH margin, degasification, flashing, pool volume/level, chemical release, chemical solubility, and strainer head loss. In general, a higher temperature is more conservative for NPSH margin, degasification, flashing, and chemical release, whereas a lower temperature is more conservative for chemical solubility and strainer head loss. Note that aluminum

precipitation was forced in the NARWHAL model if it did not occur before 24 hours (see Enclosure 3 Section 8.2 (Ref. 1, p. E3-21)), which reduces the potential impact of a lower pool temperature.

- The time when the containment spray (CS) pumps are secured affects chemical release (from unsubmerged sources) and debris accumulation on the RHR strainers. If the CS pumps are secured earlier, the precipitate quantity would be reduced, but the accumulation of debris on the RHR strainers would increase since the CS strainers would no longer be drawing any flow.
- The sump pH has competing effects since a maximum pH is more conservative for chemical release whereas a minimum pH is more conservative for chemical solubility. As described in Enclosure 2 Section 3.o, the NARWHAL model conservatively used the maximum pH for release and the minimum pH for solubility (Ref. 1, p. E2-148).
- The ECCS flow rate affects several aspects of the GSI-191 evaluation including strainer head loss, NPSH margin, time-dependent transport, penetration, and core accumulation. Higher flow rates are conservative for the strainer, but there are competing effects associated with time-dependent transport and debris penetration. In general, earlier transport to the core is more conservative, but as discussed previously, rapid formation of a filtering bed on the strainers can reduce the penetration. Also, higher ECCS flow rates result in a smaller fraction of debris accumulating at the core inlet for cold leg breaks since the accumulation is based on the ratio of the boil-off flow rate to the total ECCS flow rate.

As described in Enclosure 3 Section 14.2.3, the worse-case combinations of conditions were evaluated for strainer failure and core failure to quantify the parametric uncertainty (Ref. 1 pp. E3-66 to E3-72).

References

1. **ML17116A098.** Vogtle Electric Generating Plant - Units 1 & 2 Supplemental Response to NRC Generic Letter 2004-02. April 21, 2017.
2. **WCAP-16530-NP-A.** *Evaluation of Post-Accident Chemical Effects in Containment Sump Fluids to Support GSI-191.* March 2008 : Approved Version.