UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

April 27, 2022

Ms. Maria Lacal
Executive Vice President
and Chief Nuclear Officer
Arizona Public Service Company
Mail Station 7605
Arizona Public Service Company
P.O. Box 52034
Phoenix, AZ 85072-2034

SUBJECT: PALO VERDE NUCLEAR GENERATING STATION, UNITS 1, 2, AND 3 - CLOSEOUT OF GENERIC LETTER 2004-02, "POTENTIAL IMPACT OF DEBRIS BLOCKAGE ON EMERGENCY RECIRCULATION DURING DESIGN BASIS ACCIDENTS AT PRESSURIZED-WATER REACTORS" (EPID L-2017-LRC-0000)

Dear Ms. Lacal:

The U.S. Nuclear Regulatory Commission (NRC) issued Generic Letter (GL) 2004-02, "Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized-Water Reactors" (Agencywide Documents Access and Management System (ADAMS) Accession No. ML042360586), dated September 13, 2004, requesting that licensees address the issues raised by Generic Safety Issue (GSI)-191, "Assessment of Debris Accumulation on PWR [Pressurized Water Reactor] Sump Performance."

By letter dated May 16, 2013 (ADAMS Accession No. ML13142A034), Arizona Public Service Company (the licensee) stated that it will pursue Option 2 (deterministic) for the closure of GSI-191 and GL 2004-02 for Palo Verde Nuclear Generating Station, Units 1, 2, and 3 (Palo Verde). Subsequent to this, the licensee identified additional particulate and fibrous debris in containments, and associated evaluations were performed. The results of the evaluations were provided on December 18, 2013, and December 1, 2016. Based on these final evaluations, debris accumulation at the strainer and the resulting head loss, rather than in-vessel downstream effects (IVDEs), is design limiting. As a result, the licensee is pursuing GSI-191 closure Option 1 (see letter dated February 22, 2022; ADAMS Accession No. ML22053A240) and is resolving the in-vessel debris effects using WCAP-16793-NP-A, Revision 2, "Evaluation of Long-Term Cooling Considering Particulate, Fibrous and Chemical Debris in the Recirculating Fluid," dated July 2013 (ADAMS Accession No. ML13239A114) (final safety evaluation (SE) at ADAMS Accession No. ML13084A154) rather than WCAP-17788-P, Revision 1, "Comprehensive Analysis and Test Program for GSI 191 Closure" (ADAMS Package Accession No. ML20010F181).

The IVDEs analyses for Palo Verde, as described in the supplemental responses previously submitted to the NRC, is consistent with the methodology from Revision 2 of WCAP-16793-NP-A and its associated NRC SE.

Completion of the analysis demonstrates compliance with Title 10 of the *Code of Federal Regulations* Section 50.46(b)(5) as it relates to in-vessel downstream debris effects for Palo Verde.

On July 23, 2019 (ADAMS Package Accession No. ML19203A303), GSI-191 was closed. It was determined that the technical issues identified in GSI-191 were now well understood, and therefore, GSI-191 could be closed. Prior to and in support of closing GSI-191, the NRC staff issued a technical evaluation report on IVDEs (ADAMS Accession Nos. ML19178A252 and ML19073A044 (not publicly available, proprietary information)). Following the closure of GSI-191, the NRC staff also issued review guidance for IVDEs, "NRC Staff Review Guidance for In-Vessel Downstream Effects Supporting Review of GL 2004-02 Responses" (ADAMS Accession No. ML19228A011), to support review of the GL 2004-02 responses.

The NRC staff has reviewed the licensee's responses and supplements associated with GL 2004-02. Based on the evaluations, the NRC staff finds the licensee has provided adequate information as requested by GL 2004-02.

The stated purpose of GL 2004-02 was focused on demonstrating compliance with 10 CFR 50.46. Specifically, GL 2004-02 requested addressees to perform an evaluation of the emergency core cooling system and containment spray system recirculation and, if necessary, take additional action to ensure system function in light of the potential for debris to adversely affect long-term core cooling. The NRC staff finds the information provided by the licensee demonstrates that debris will not inhibit the emergency core cooling system or containment spray system performance following a postulated loss-of-coolant accident. Therefore, the ability of the systems to perform their safety functions, to assure adequate long term core cooling following a design-basis accident, as required by 10 CFR 50.46, has been demonstrated.

Therefore, the NRC staff finds the licensee's responses to GL 2004-02 are adequate and considers GL 2004-02 closed for Palo Verde.

Enclosed is the summary of the NRC staff's review. If you have any questions, please contact me at (301) 415-1564 or by e-mail at Siva.Lingam@nrc.gov.

Sincerely,

/RA/

Siva P. Lingam, Project Manager
Plant Licensing Branch IV
Division of Operating Reactor Licensing
Office of Nuclear Reactor Regulation

Docket Nos. STN 50-528, STN 50-529,
and STN 50-530

Enclosure:
NRC Staff Review of GL 2004-02

cc: Listserv

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

U.S. NUCLEAR REGULATORY COMMISSION STAFF REVIEW

OF THE DOCUMENTATION PROVIDED BY

ARIZONA PUBLIC SERVICE COMPANY

FOR PALO VERDE NUCLEAR GENERATING STATION, UNITS 1, 2, AND 3

DOCKET NOS. STN 50-528, STN 50-529, AND 50-530

CONCERNING RESOLUTION OF GENERIC LETTER 2004-02

POTENTIAL IMPACT OF DEBRIS BLOCKAGE ON EMERGENCY RECIRCULATION DURING

DESIGN-BASIS ACCIDENTS AT PRESSURIZED-WATER REACTORS

1.0 INTRODUCTION

A fundamental function of the emergency core cooling system (ECCS) is to recirculate water that has collected at the bottom of the containment through the reactor core following a break in the reactor coolant system (RCS) piping to ensure long-term removal of decay heat from the reactor fuel. Leaks from the RCS, hypothetical scenarios known as loss-of-coolant accidents (LOCAs), are part of every plant's design basis. Hence, nuclear plants are designed and licensed with the expectation that they are able to remove reactor decay heat following a LOCA to prevent core damage. Long-term cooling following a LOCA is a basic safety function for nuclear reactors. The recirculation sump provides a water source to the ECCS in a pressurized-water reactor (PWR) once the primary water source has been depleted.

If a LOCA occurs, piping thermal insulation and other materials may be dislodged by the two-phase coolant jet emanating from the broken RCS pipe. This debris may transport, via flows coming from the RCS break or from the containment spray system (CSS) to the pool of water that collects at the bottom of containment following a LOCA. Once transported to the sump pool, the debris could be drawn toward the ECCS sump strainers, which are designed to prevent debris from entering the ECCS and the reactor core. If this debris were to clog the strainers and prevent coolant from entering the reactor core, containment cooling could be lost and result in core damage and containment failure.

It is also possible that some debris would pass through (termed "bypass") the sump strainer and lodge in the reactor core. This could result in reduced core cooling and potential core damage. If the ECCS strainer were to remain functional, even with core cooling reduced, containment cooling would be maintained, and the containment function would not be adversely affected.

Findings from research and industry operating experience raised questions concerning the adequacy of PWR sump designs. Research findings demonstrated that, compared to other LOCAs, the amount of debris generated by a high-energy line break (HELB) could be greater. The debris from a HELB could also be finer (and thus more easily transportable) and could be comprised of certain combinations of debris (i.e., fibrous material plus particulate material) that could result in a substantially greater flow restriction than an equivalent amount of either type of debris alone. These research findings prompted the U.S. Nuclear Regulatory Commission (NRC) to open Generic Safety Issue (GSI)-191, "Assessment of Debris Accumulation on PWR Sump Performance," in 1996. This resulted in new research for PWRs in the late 1990s.

GSI-191 focuses on reasonable assurance that the provisions of Title 10 of the *Code of Federal Regulations* (10 CFR) Section 50.46(b)(5) are met. This deterministic rule requires maintaining long-term core cooling (LTCC) after initiation of the ECCS. The objective of GSI-191 is to ensure that post-accident debris blockage will not impede or prevent the operation of the ECCS and CSS in recirculation mode at PWRs during LOCAs or other HELB accidents for which sump recirculation is required. The NRC completed its review of GSI-191 in 2002 and documented the results in a parametric study that concluded that sump clogging at PWRs was a credible concern.

GSI-191 concluded that debris clogging of sump strainers could lead to recirculation system ineffectiveness as a result of a loss of net positive suction head (NPSH) for the ECCS and CSS recirculation pumps. Resolution of GSI-191 involves two distinct but related safety concerns: (1) potential clogging of the sump strainers that results in ECCS and/or CSS pump failure; and (2) potential clogging of flow channels within the reactor vessel because of debris bypass of the sump strainer (in-vessel effects). Clogging at either the strainer or in-vessel channels can result in loss of the long-term cooling safety function.

After completing the technical assessment of GSI-191, the NRC issued Bulletin 03-01, "Potential Impact of Debris Blockage on Emergency Sump Recirculation at Pressurized-Water Reactors" (Agencywide Documents Access and Management System (ADAMS) Accession No. ML031600259), on June 9, 2003. The Office of Nuclear Reactor Regulation (NRR) requested and obtained the review and endorsement of the bulletin from the Committee to Review Generic Requirements (CRGR) (ADAMS Accession No. ML031210035). As a result of the emergent issues discussed in Bulletin 03-01, the NRC staff requested an expedited response from PWR licensees on the status of their compliance of regulatory requirements concerning the ECCS and CSS recirculation functions based on a mechanistic analysis. The NRC staff asked licensees who chose not to confirm regulatory compliance, to describe any interim compensatory measures that they had implemented or will implement to reduce risk until the analysis could be completed. All PWR licensees responded to Bulletin 03-01. The NRC staff reviewed all licensees' Bulletin 03-01 responses and found them acceptable.

In developing Bulletin 03-01, the NRC staff recognized that it might be necessary for licensees to undertake complex evaluations to determine whether regulatory compliance exists in light of the concerns identified in the bulletin and that the methodology needed to perform these evaluations was not currently available. As a result, that information was not requested in Bulletin 03-01, but licensees were informed that the NRC staff was preparing a Generic Letter (GL) that would request this information. GL 2004-02, "Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized-Water Reactors," dated September 13, 2004 (ADAMS Accession No. ML042360586), was the follow-on information request referenced in Bulletin 03-01.

This document set the expectations for resolution of PWR sump performance issues identified in GSI-191, to ensure the reliability of the ECCS and CSS at PWRs. NRR requested and obtained the review and endorsement of the GL from the CRGR (ADAMS Accession No. ML040840034).

GL 2004-02 requested that addressees perform an evaluation of the ECCS and CSS recirculation functions in light of the information provided in the letter and, if appropriate, take additional actions to ensure system function. Additionally, addressees were requested to submit the information specified in GL 2004-02 to the NRC. The request was based on the identified potential susceptibility of PWR recirculation sump screens to debris blockage during design-basis accidents (DBAs) requiring recirculation operation of ECCS or CSS and on the potential for additional adverse effects due to debris blockage of flow paths necessary for ECCS and CSS recirculation and containment drainage. GL 2004-02 required addressees to provide the NRC a written response in accordance with 10 CFR 50.54(f).

By letter dated May 28, 2004 (ADAMS Accession No. ML041550661), the Nuclear Energy Institute (NEI) submitted NEI 04-07, “Pressurized Water Reactor Sump Performance Evaluation Methodology” (ADAMS Accession Nos. ML050550138 and ML050550156), which describes a methodology for use by PWR licensees in the evaluation of containment sump performance. This is also called the Guidance Report (GR). NEI requested that the NRC review the methodology. The methodology was intended to allow licensees to address and resolve GSI-191 issues in an expeditious manner through a process that starts with a conservative baseline evaluation. The baseline evaluation serves to guide the analyst and provide a method for quick identification and evaluation of design features and processes that significantly affect the potential for adverse containment sump blockage for a given plant design. The baseline evaluation also facilitates the evaluation of potential modifications that can enhance the capability of the design to address sump debris blockage concerns and uncertainties and supports resolution of GSI-191. The report offers additional guidance that can be used to modify the conservative baseline evaluation results through revision to analytical methods or through modification to the plant design or operation.

By letter dated December 6, 2004 (ADAMS Accession No. ML043280641), the NRC issued an evaluation of the NEI methodology. The NRC staff concluded that the methodology, as approved in accordance with the NRC staff safety evaluation (SE), provides an acceptable overall guidance methodology for the plant-specific evaluation of the ECCS or CSS sump performance following postulated DBAs. Taken together NEI 04-07 and the associated NRC staff SE are often referred to as the GR/SE.

In response to the NRC staff SE conclusions on NEI 04-07, the Pressurized Water Reactor Owners Group sponsored the development of the following Westinghouse Commercial Atomic Power (WCAP) Topical Reports (TRs):

- TR-WCAP-16406-P-A, “Evaluation of Downstream Sump Debris Effects in Support of GSI-191,” Revision 1 (not publicly available, proprietary information), to address the effects of debris on piping systems and components (NRC Final SE at ADAMS Accession No. ML073520295).

- TR-WCAP-16530-NP-A, "Evaluation of Post-Accident Chemical Effects in Containment Sump Fluids to Support GSI-191," dated March 2008 (ADAMS Accession No. ML081150379), to provide a consistent approach for plants to evaluate the chemical effects that may occur post-accident in containment sump fluids (NRC Final SE at ADAMS Package Accession No. ML073521294).

- TR-WCAP-16793-NP-A, "Evaluation of Long-Term Cooling Considering Particulate, Fibrous and Chemical Debris in the Recirculating Fluid," Revision 2, dated July 2013 (ADAMS Accession No. ML13239A114), to address the effects of debris on the reactor core (NRC Final SE at ADAMS Accession No. ML13084A154).

The NRC staff reviewed the TRs and found them acceptable to use (as qualified by the limitations and conditions stated in the respective SEs). A more detailed evaluation of how the TRs were used by the licensee is contained in the evaluations below.

After the NRC staff evaluated licensee responses to GL 2004-02, the staff found that there was a misunderstanding between the industry and the NRC on the level of detail necessary to respond to GL 2004-02. The NRC staff, in concert with stakeholders, developed a content guide for responding to requests for additional information (RAIs) concerning GL 2004-02. By letter dated August 15, 2007 (ADAMS Accession No. ML071060091), the NRC issued the content guide describing the necessary information to be submitted to allow the NRC staff to verify that each licensee's analyses, testing, and corrective actions associated with GL 2004-02 are adequate to demonstrate that the ECCS and CSS will perform their intended function following any DBA. By letter dated November 21, 2007 (ADAMS Accession No. ML073110389), the NRC issued a revised content guide (hereafter referred to as the content guide).

The content guide described the following information needed to be submitted to the NRC:

- corrective actions for GL 2004-02,
- break selection,
- debris generation/zone of influence (ZOI) (excluding coatings),
- debris characteristics,
- latent debris,
- debris transport,
- head loss and vortexing,
- NPSH,
- coatings evaluation,
- debris source term,
- screen modification package,
- sump structural analysis,
- upstream effects,
- downstream effects – components and systems,
- downstream effects – fuel and vessel,
- chemical effects, and
- licensing basis

Based on the interactions with stakeholders and the results of the industry testing, the NRC staff, in 2012, developed three options to resolve GSI-191.

These options were documented and proposed to the Commission in SECY-12-0093, "Closure Options for Generic Safety Issue-191, Assessment of Debris Accumulation on Pressurized-Water Reactor Sump Performance," dated July 9, 2012 (ADAMS Accession No. ML121320270). The options are summarized as follows:

- Option 1 would require licensees to demonstrate compliance with 10 CFR 50.46, "Acceptance criteria for emergency core cooling systems for light-water nuclear power reactors," through approved models and test methods. These will be low fiber plants with less than 15 grams of fiber per fuel assembly.

- Option 2 requires implementation of additional mitigating measures and allows additional time for licensees to resolve issues through further industry testing or use of a risk-informed approach.

    - Option 2 Deterministic: Industry to perform more testing and analysis and submit the results for NRC review and approval (in-vessel only).

    - Option 2 Risk Informed: Use the South Texas Project pilot approach currently under review with NRR staff.

- Option 3 involves separating the regulatory treatment of the sump strainer and in-vessel effects.

The options allowed industry alternative approaches for resolving GSI-191. The Commission issued Staff Requirements Memorandum SECY-12-0093 on December 14, 2012 (ADAMS Accession No. ML12349A378), approving all three options for closure of GSI-191.

By letter dated May 16, 2013 (ADAMS Accession No. ML13142A034), Arizona Public Service Company (the licensee) stated that it will pursue Option 2 (deterministic) for the closure of GSI-191 and GL 2004-02 for Palo Verde Nuclear Generating Station, Units 1, 2, and 3 (Palo Verde).

Subsequent to this, the licensee identified additional particulate and fibrous debris in containments and associated evaluations were performed. The results of the evaluations were provided on December 18, 2013, and December 1, 2016, as indicated in the table below. Based on these final evaluations, debris accumulation at the strainer and the resulting head loss, rather than in-vessel downstream effects (IVDEs), is design limiting. As a result, the licensee is pursuing GSI-191 closure Option 1 (see ADAMS Accession No. ML22053A240 dated February 22, 2022) and is resolving the in-vessel debris effects using the methodology in WCAP-16793-NP-A, Revision 2, rather than WCAP-17788-P, Revision 1, "Comprehensive Analysis and Test Program for GSI-191 Closure" (ADAMS Package Accession No. ML20010F181).

The IVDEs analyses for Palo Verde as described in the supplemental responses previously submitted to the NRC is consistent with the methodology from Revision 2 of WCAP-16793-NP-A and its associated SE. Completion of the analysis demonstrates compliance with 10 CFR 50.46(b)(5) as it relates to in-vessel downstream debris effects for Palo Verde.

On July 23, 2019 (ADAMS Package Accession No. ML19203A303), GSI-191 was closed. It was determined that the technical issues identified in GSI-191 were now well understood and therefore, GSI-191 could be closed.

Prior to and in support of closing GSI-191, the NRR staff issued a technical evaluation report on IVDEs (ADAMS Accession Nos. ML19178A252 and ML19073A044 (not publicly available, proprietary information)). Following the closure of GSI-191, the NRR staff also issued review guidance for IVDEs to support review of the GL 2004-02 responses, "NRC Staff Review Guidance for In-Vessel Downstream Effects Supporting Review of Generic Letter 2004-02 Responses" (ADAMS Accession No. ML19228A011).

The following is a list of documentation provided by the licensee in response to GL 2004-02 for Palo Verde:

GL 2004-02 CORRESPONDENCE		
DOCUMENT DATE	**ACCESSION NO.**	**DOCUMENT**
March 4, 2005	ML050740440	Initial Response to GL
June 2, 2005	ML051520267	1st NRC RAI
July 9, 2005	ML052030335	Licensee Response to RAI
September 1, 2005	ML052500306	Supplemental Information
February 9, 2006	ML060390350	2nd NRC RAI
February 29, 2008	ML080710546	Licensee Response to RAI
December 16, 2008	ML083430549	3rd NRC RAI
March 13, 2009	ML090830334	Licensee Response to RAI
January 7, 2010	ML100070645	4th NRC RAI
May 16, 2013	ML13142A034	Closure Option1
December 18, 2013	ML13357A218	Licensee Response to RAI
December 1, 2016	ML16340A988	Addendum to Supplemental Response
February 22, 2022	ML22053A240	Final Response

The NRC staff reviewed the information provided by the licensee in response to GL 2004-02 and all RAIs. The following is a summary of the NRC staff review.

2.0 GENERAL DESCRIPTION OF CORRECTIVE ACTIONS FOR THE RESOLUTION OF GL-2004-02

GL 2004-02 Requested Information Item 2(b) requested a general description of and implementation schedule for all corrective actions. The following is a list of corrective actions completed by the licensee at Palo Verde, in support of the resolution of GL 2004-02.

- Performed downstream effects evaluation using the WCAP-16406-P-A, Revision 1 methodology.
- Performed containment walkdowns using the guidance of NEI 02-01, "Condition Assessment Guidelines: Debris Sources Inside PWR Containments," dated April 19, 2002 (ADAMS Package Accession No. ML021490241).
- Enhanced the modification and maintenance processes relative to GL 2004-02 controls to insure operability of the containment sumps.
- Installed new ECCS sump strainers in Palo Verde (≈3,142 square feet (ft^2) each (two strainers per unit)).

- Confirmed ECCS sump strainer performance through prototype chemical precipitates head loss test.

- Assessed the impact and resolution of newly-discovered Microtherm, Temp-Mat, and known Nukon insulation that was not considered in the initial head loss evaluation. The assessment included the effects on chemical precipitate loads that could occur following a LOCA.

- Removed a majority of the newly discovered Temp-Mat insulation.

- Removed all of the Nukon insulation that had not been considered in the initial chemical effects evaluation. (This insulation was not within a ZOI but could have been submerged and contributed to chemical effects.)

- Performed comparative analysis for new sump strainers (to assess newly-discovered Microtherm, and Temp-Mat that was discovered and not removed).

- Augmented results of strainer margin study by additional, new analysis that provides increased sump strainer structural capacity.

- Increased refueling water tank (RWT) minimum water level to ensure adequate strainer submergence.

- Inspected representative sample of RCS piping, including hot and cold legs, pressurizer surge and main spray lines, and removed discrepant (i.e., not evaluated) fibrous insulation.

Based on the information provided by the licensee, the NRC staff considers this item closed for GL 2004-02 for Palo Verde.

3.0 BREAK SELECTION

The objective of the break selection process is to identify the break size and locations that present the greatest challenge to post-accident sump performance. The term “ZOI” used in this section refers to the spherical zone representing the volume of space affected by the ruptured piping.

NRC Staff Review

The NRC staff review is based on documentation provided by the licensee on March 13, 2009, and the updated supplement dated December 18, 2013. The review also considered the information provided by the licensee in its December 1, 2016, addendum. There were no RAIs regarding break selection and no significant changes regarding break selection between supplements. The guidance documents used for the review include the revised content guide, Regulatory Guide (RG) 1.82, “Water Sources for Long-Term Recirculation Cooling Following a Loss-of-Coolant Accident,” Revision 4, dated March 2012 (ADAMS Accession No. ML111330278), and the NEI 04-07 GR and the associated NRC GR/SE.

The licensee used the GR/SE for break selection, with the exception that the break was not moved incrementally along the pipe to determine the location, which resulted in the maximum debris generation. Instead, the licensee used a discrete approach to determine the break locations to analyze.

The break locations analyzed by the licensee maximize the amount and types of debris generated. The breaks analyzed were near large debris sources next to walls and floors such as a steam generator (SG), reactor coolant pumps, and the pressurizer. Breaks located where debris would be more easily transported to the strainers, as it would be from the D-ring SG compartment closer to the recirculation sumps/strainers, were also analyzed. Three specific breaks analyzed in the primary loop piping are: both of the 30 inch diameter (D) cold leg suction lines at the reactor coolant pumps in the SG compartment nearest the recirculation sumps and one in the 42-inch hot leg at the SG #2 nozzle also in the SG compartment nearest the recirculation sumps (the limiting break). These three breaks are the largest pipes with breaks that would result in the largest ZOI. These three breaks bound smaller breaks at the safety injection (SI) and shutdown cooling (SDC) injection lines (both 14-inch inside diameter) and the SDC suction line (16-inch inside diameter) located within the SG D-ring.

The licensee stated that breaks in the pressurizer enclosure have the potential for creating a greater quantity of fiber insulation debris than other analyzed breaks due to the types of insulation located there (Nukon and Temp-Mat). Due to this, the licensee specifically analyzed a break in the 4-inch pressurizer spray line inside the pressurizer cavity even though the break size is small. The pressurizer surge line was not analyzed for debris contribution since there is a steel skirt surrounding the surge line nozzle meaning a break in that location would not lead to significant debris.

When breaks are selected adjacent to the larger insulated components and in close proximity with other large pipes and wall, floor and structural steel surfaces, they are expected to result in the largest amounts of various types of debris generated. The NRC staff finds the licensee's method of choosing the limiting break locations that present the greatest challenge to post-accident sump performance acceptable.

In addition to the above, secondary breaks were not considered in the break selection process because they do not result in recirculation for any design basis HELBs. This is in accordance with the NRC staff-approved guidance in the GR/SE.

In its addendum to the supplemental response, the licensee stated that breaks in the reactor cavity had not been previously analyzed because it was thought that the reactor and piping within the cavity was insulated with reflective metal insulation (RMI). However, upon discovery that the reactor is insulated with Microtherm, the licensee reconsidered breaks in the reactor cavity.

The licensee stated that the following three debris generation location cases were considered in assessment of the newly-discovered insulation:

- Break Case 1: Hot leg break at Loop 2 SG (the original, S1, bounding break location)
- Break Case 2: Cold leg reactor pressure vessel (RPV) nozzle break (new)
- Break Case 3: Hot leg RPV nozzle break (new)

These breaks were adequately evaluated, and the amount of Microtherm and its effects are discussed further in the debris generation and head loss sections.

NRC Staff Conclusion

For this review area, the licensee provided sufficient information such that the NRC staff has reasonable assurance that the subject review area has overall been addressed conservatively or prototypically. The break location analysis completed by the licensee is in accordance with the content guide and the GR/SE while using a discrete approach to determine break locations to analyze for maximum debris generation results. Therefore, the NRC staff concludes that the break selection evaluation for Palo Verde is acceptable. Based on the information provided by the licensee, the NRC staff considers this area closed for GL 2004-02 for Palo Verde.

4.0 DEBRIS GENERATION/ZONE OF INFLUENCE (EXCLUDING COATINGS)

The objective of the debris generation/ZOI evaluation is to determine the limiting amounts and combinations of debris that can occur from the postulated breaks in the RCS.

NRC Staff Review

The NRC staff review is based on the licensee's RAI responses and supplemental information through December 18, 2013, as supplemented by the December 1, 2016, addendum submittal.

The debris generation/ZOI evaluation conducted by the licensee was performed adequately and provided the information specified in the content guide. The licensee used the GR Section 4.2.2.1.1 ZOI refinement of debris-specific spherical ZOI. The licensee also used the default ZOI of 28.6D for its Mirror RMI and Thermo-lag 330, the default value of 17.0D for Nukon (jacketed and unjacketed), and 11.7D for Temp-Mat with stainless steel wire retainer as specified in the GR/SE.

In its February 29, 2008 submittal, the licensee indicated that it assumed the approved methodology GR/SE default ZOI value of 2D for its Transco RMI, of 28.6D for its Mirror RMI, the default value of 17.0D for its Nukon (jacketed and unjacketed), and 11.7D for its Temp-Mat with stainless steel retainer. The licensee also assumed a ZOI of 17.0D for its Thermo-lag 330. The ZOI for encapsulated Microtherm was assumed to be 2D, as justified by testing of RMI cassette of similar construction. However, the ZOI for restrained breaks (all breaks in the reactor cavity) was increased by a safety factor of 2 so that the basic ZOI used is actually about 4D.

The NRC staff review found one issue with the debris generation/ZOI evaluation. The licensee credited a ZOI of 17.0D for Thermo-lag 330. The licensee stated that Thermo-lag 330 was a robust particulate material with fiber binders that would have a destructive pressure equal to or greater than the Nukon insulation.

The NRC requested that the licensee describe the basis for the assumed ZOI of 17.0D (break diameter) for Thermo-lag. The NRC staff asked if all the Thermo-lag in a SG compartment or the pressurizer compartment were within the ZOI, how much would the debris totals increase. The licensee responded to this RAI on March 13, 2009, by changing its ZOI to 28.6D for Thermo-lag 330, which is the maximum ZOI recommended for any insulation type as specified in the GR/SE.

On December 1, 2016, the licensee provided a supplemental response to address the newly discovered Microtherm, Temp-Mat, and Nukon insulation, which were discovered in April 2015, spring 2016, and fall 2015, respectively.

The licensee stated the debris generation analysis did not explicitly consider breaks at the RPV nozzles as it was incorrectly assumed that the RPV and piping insulation was RMI. Therefore, the licensee provided break locations considered in this qualification analysis in Figure 4-2 of its December 1, 2016, supplement, which included six break locations at the RPV nozzles.

The licensee stated that at the time of its December 18, 2013, submittal, all Microtherm at Palo Verde was thought to have been removed, which is why that supplement did not discuss a ZOI for Microtherm. The licensee stated that the ZOI of Microtherm insulation encapsulation cassettes is 2.00D, corresponding to a destruction pressure of 114 pounds per square inch gauge. The 2.00D ZOI is applicable for unrestrained break situations. For situations where the axial and/or radial separation at the break is restrained, an alternate method of computing ZOI, based on the destruction pressure, is applied.

The licensee stated that for restrained breaks, the circumferential break with ends restrained is the most conservative because due to its 360-degree cylindrical shape, it will result in more destruction of encapsulated Microtherm and Temp-Mat on the RPV than the circumferential break with unrestrained ends or the longitudinal break. The licensee calculated the restrained break ZOIs as shown in the table below:

Item	Microtherm	Temp-Mat	Description
ZOI_{nom}	2.00D	11.70D	Applicable to D-ring break cases
ZOI_{calc} Cold Leg Break	1.54D	9.00D	Used for RPV nozzle break cases
ZOI_{calc} Hot Leg Break	1.32D	8.42D	Used for RPV nozzle break cases
ZOI_{calc} Cold Leg Break	n/a	2.86D	Used for RPV nozzle break cases to define sub-region of total ZOI for refined (fines/small) size distribution
ZOI_{calc} Hot Leg Break	n/a	2.45D	

The licensee stated that for debris generation calculations for RPV nozzle breaks, the spherical volume of the ZOI is conformed to an equivalent volume having the “pancake-saddle” shape of the region between the RPV and concrete biological shield wall surrounding the RPV. This results in a greater reach of the ZOI and a larger quantity of insulation affected than if the ZOI was considered spherical.

The licensee stated that all destroyed Microtherm is considered to be fines. The licensee also stated that since all newly-discovered Temp-Mat in the D-ring SG sub-compartments will be or has been removed, no newly-discovered Temp-Mat is destroyed due to breaks in the D-rings. The size distribution of Temp-Mat destroyed by breaks at RPV nozzles is based on results in proprietary document ALION-REP-ALION-2806-01, “Insulation Debris Size Distribution for Use in GSI-191 Resolution,” Revision 4, May 20, 2009, and is based on two sub-regions of the overall ZOI, 3.7D and 3.7D-11.7D ZOI. The size distribution for Temp-Mat was reviewed by the NRC during its audit at Indian Point and found to be an acceptable method that was based on NEI 04-07 GR and the associated staff GR/SE. Therefore, it is acceptable for Palo Verde to use this method.

The licensee stated that the debris generation analysis of a break at the Loop-2 SG (Break Case 1) was based on the following:

- Considers removal of Temp-Mat on cross-over piping and at resistance-temperature detectors on cold legs in both loops.
- Considers no jet impinges on RPV through D-ring wall opening on Microtherm band around RPV based on being outside the 2.00D ZOI.
- Considers no jet impingement on Temp-Mat on the RPV at the Microtherm to RMI transition based on robust barrier.
- Considers no debris is generated in Loop-1 based on robust barrier.
- For chemical effects,
- Considers that the reactor cavity will flood and flow to the D-ring via 4-inch diameter pipe 051-XCDA
- Considers removal of Nukon insulation

The licensee stated that debris generation analysis of breaks at RPV nozzles (Break Cases 2 and 3) was based on the following:

- Considers blowdown to D-rings and reactor cavity based on flow area ratios.
- Considers Microtherm destruction based on restrained separation of ruptured pipe and RPV nozzle.
- Considers all Temp-Mat at RPV cold-leg discharge elbows is removed.
- Assumes Temp-Mat on affected cold-leg at resistance-temperature detectors has been removed.

The NRC reviewed these assumptions and found them to be consistent with plant conditions that will exist when the licensee has removed insulation that either has been or is planned for removal. The analyses are consistent with the NEI 04-07 GR and the associated staff GR/SE.

The licensee provided debris generation results in Table 4-5, "Temp-Mat and Microtherm Debris Generation Results," of its December 1, 2016, addendum. The amounts provided included blowdown transport so that the results were amounts of debris generated to either within or outside of the reactor cavity. These amounts are in addition to the amounts calculated prior to the discovery of the additional insulation. The amounts provided here also include erosion of non-transportable Temp-Mat. The limiting break scenario resulted in 1.8 cubic feet (ft^3) of Temp-Mat fines generated to the reactor cavity, 0.7 ft^3 of Temp-Mat fines generated to the D-ring, and 16.8 ft^3 of Microtherm in the cavity.

The NRC staff notes that all Temp-Mat in the D-rings has been removed and any undocumented Temp-Mat within the D-ring will be removed based on licensee commitments. However, due to RPV nozzle breaks, a portion of the Temp-Mat in the region below the RPV nozzles blows down to the D-ring, and then is assumed to transport to the sump strainers, depending on flow scenario and associated transport fractions.

The NRC staff also notes that the blowdown location of Microtherm is not significant because all fines, regardless of location, are considered to transport 100 percent to the sump strainer.

The NRC staff reviewed the additional information provided by the licensee in its December 1, 2016, addendum closely, because it contains some alternate methods of calculating debris generation. The NRC staff verified that the cassettes containing Microtherm at Palo Verde are constructed at least as robustly as those that were tested to determine ZOIs for RMI that were accepted by the NRC staff in its GR/SE.

Therefore, the assumption of a 2D ZOI for Microtherm encapsulated in cassettes at Palo Verde including the safety factor of 2 is accepted by the NRC staff. For fully offset breaks (outside the reactor cavity) at Palo Verde the assumption of a 2D ZOI for Microtherm is accepted because it is unlikely that a break outside the cavity will damage encapsulated Microtherm on the reactor due to the robust reactor cavity wall between the break and the insulation. The ZOIs calculated for restrained breaks for Microtherm and Temp-Mat were determined using guidance from the boiling-water reactor (BWR) Utility Resolution Guidance for ECCS Suction Strainer Blockage. This methodology has been accepted by the NRC staff for BWRs and has also been applied to PWRs and accepted by the staff for conditions similar to Palo Verde's reactor cavity breaks.

NRC Staff Conclusion

For the debris generation/ZOI review area, the licensee provided information such that the NRC staff has reasonable assurance that the subject review area has been addressed conservatively or prototypically. Specifically, the licensee used NRC approved methodologies to determine the ZOIs at Palo Verde. Therefore, the NRC staff concludes that the debris generation evaluation for Palo Verde is acceptable. The NRC staff considers this item closed for GL 2004-02.

5.0 DEBRIS CHARACTERISTICS

The objective of the debris characteristics determination process is to establish a conservative debris characteristics profile for use in determining the transportability of debris and its contribution to strainer head loss.

NRC Staff Review

The NRC staff review was based on documentation provided by the licensee through February 29, 2008. The final review is based on the licensee's RAI responses and supplemental information through December 18, 2013.

The licensee based its debris characteristics on the GR/SE and manufacturer data. In addition to the debris size distributions, the licensee provided tables of applicable material densities.

The size distributions for the different type of debris applicable to Palo Verde are as follows:

- RMI: Section 3.4.3.3.2 of the GR recommends using a size distribution of 75 percent small fines and 25 percent large pieces, where small pieces are defined as anything less than 4 inches. Section 3.2.2.4 of NUREG/CR-6808 "Parametric Study of the Potential for ECCS Strainer Blockage Due to LOCA Generated Debris" (ADAMS Accession No. ML083290498), refines the small pieces distribution further: 5 percent are fines/particulate (less than or equal to (≤)1/4 inches) and 70 percent are greater than (>) 1/4 inches but less than (<) 4 inches.

- Low density fiberglass (Nukon) and high density fiberglass (Temp-Mat) Insulations: Sections 3.4.3.3.1 and 3.4.3.3.2 of the GR recommends that 60 percent of all fibrous material within the ZOI becomes small fines (40 percent becomes large/intact pieces).

- Thermo-lag 330: Section 3.4.3.3.1 of the GR recommends modeling this debris as 100 percent small fines.

- Coatings: Section 3.4.3.3 of the GR states that all qualified coatings within the ZOI are considered small fines, which is also applied to all unqualified coatings and all qualified damaged coatings outside the ZOI. All qualified coatings outside the ZOI will remain intact. Coatings inside the ZOI are assumed to fail as 10 micrometer particles per the GR/SE guidance.

- Latent debris: Section 3.6.3 of the GR recommends that all debris generated outside the ZOI is small fine debris.

The NRC staff review found one issue concerning the licensee's treatment of Thermo-lag 330 debris in the analysis and during head loss testing. The licensee's response did not adequately address the NRC staff's February 9, 2006, RAI on a technical basis because the debris size distribution assumed by the licensee was arbitrary and appeared potentially non-conservative.

On December 16, 2008, the NRC issued an RAI requesting the licensee to provide a listing of the materials that make up Thermo-lag 330, as well as the bulk and material densities of Thermo-lag 330 in its installed condition. The NRC also requested that the licensee justify the use of any surrogate materials used to represent Thermo-lag 330 for head-loss testing.

On March 13, 2009, the licensee responded to this RAI by providing a material safety data sheet for the material and providing a general citation to material properties provided in WCAP-16530-NP, which lists silicon dioxide, fiberglass, and epoxides as main constituents. The licensee stated that no surrogate material was used for the latest testing; actual Thermo-lag was used. The licensee stated a new assumption, that Thermo-lag debris could be modeled as a combination of equal-area-distributed pieces measuring 1 inch × 1 inch, 2 inches × 2 inches, 3 inches × 3 inches, and some undefined quantity fines generated from cutting these pieces and mixing them using a high-pressure water jet prior to head loss testing.

On January 7, 2010, the NRC issued another RAI regarding this issue. The NRC staff stated that the only important size of Thermo-lag as far as strainer head loss is fines. The NRC stated that the amount of Thermo-lag material generated and added to the head loss tests in the form of true fines was unknown. Based on the information provided, the NRC staff found that, due to the debris preparation methods used, the fraction of fines was low.

The NRC staff determined that this issue should be considered within the broader context of how the licensee treated Thermo-lag, as well as the overall strainer analysis. To support the first round of testing, the licensee assumed a 17D ZOI for Thermo-lag and appeared to have used a surrogate of 5 percent Nukon fiber and 95 percent particulate to model this debris for head loss testing.

A head loss greater than 10 feet was measured in this test. An RAI was asked (in the Debris Generation Section) because there was not a substantial basis for the 17D ZOI for Thermo-lag. Rather than attempting to justify the Thermo-lag ZOI and surrogate debris approach, the licensee expanded the Thermo-lag ZOI to the GR/SE default value of 28.6D and substantially reduced the conservatism in the size distribution for the destroyed material.

On December 18, 2013, the licensee provided additional information regarding Thermo-lag fine debris preparation and distance of Thermo-lag from potential pipe breaks. The NRC staff determined that the Thermo-lag was relatively distant from break locations, and robust in construction making it unlikely that a significant amount would be generated by a LOCA jet.

Based on this response, the NRC considers the debris characteristics issues for Thermo-lag resolved.

The NRC staff concludes that the debris characteristics evaluation for Palo Verde is acceptable when compared to the staff approved methods and guidance documents.

NRC Staff Conclusion

For the debris characteristics review area, the licensee provided information such that the NRC staff has reasonable assurance that the subject review area has overall been addressed conservatively or prototypically. The NRC staff considers this item closed for GL 2004-02 for Palo Verde.

6.0 LATENT DEBRIS

The objective of the latent debris evaluation process is to provide a reasonable approximation of the amount and types of latent debris (e.g., miscellaneous fiber, dust, dirt) existing within the containment and its potential impact on sump screen head loss.

NRC Staff Review

The guidance documents used for the review include the content guide, the GR/SE, and NEI 02-01.

The licensee performed a detailed walkdown for transportable debris in the containment building in each unit. In accordance with recommendations in NEI 02-01, samples at discreet locations were collected and documented in the walkdown reports. The walkdowns inventoried the amounts and types of materials that could become transportable and could contribute to sump blockage or cause detrimental effects if allowed to pass the sump strainer. Latent debris calculations and the latent debris head loss properties used by the licensee were based on NRC staff approved methodologies.

The sample results, when extrapolated to the entire containment buildings, resulted in total latent debris masses as follows:

- Unit 1 - The total weight of latent debris in containment is 101.17 pounds (lbs)
- Unit 2 - The total weight of latent debris in containment is 119.21 lbs.
- Unit 3 - The total weight of latent debris in containment is 105.82 lbs.

Fifteen percent of the latent debris was assumed to be fiber in accordance with the NEI 04-07 GR and the associated NRC staff GR/SE. A conservative value of 200 lbs of latent debris was assumed in the strainer head loss testing.

The total strainer surface area is 3,142 ft^2 per sump. The licensee determined that the maximum quantity of miscellaneous material that could transport to the strainer is 88 ft^2. The licensee conservatively rounded this value to 100 ft^2 for conservatism.

A sacrificial strainer surface area of 400 ft^2 was conservatively assumed for chemical effects testing and head loss analysis. The sacrificial area is retained on the strainer surface area for labels, tags, stickers, placards and other miscellaneous or foreign materials.

The sacrificial strainer surface area of 400 ft^2 is greater than the recommended 75 percent of the total foreign material debris area as described in the GR/SE.

Based on the above the NRC staff finds that the licensee used conservative values and approved methodologies in the evaluation of latent debris at Palo Verde.

NRC Staff Conclusion

For the latent debris review area, the licensee provided information such that the NRC staff has reasonable assurance that the subject review area has been addressed conservatively or prototypically. The NRC staff considers the latent debris area to be adequately evaluated by the licensee. Therefore, the NRC staff considers this item closed for GL 2004-02 for Palo Verde.

7.0 DEBRIS TRANSPORT

The objective of the debris transport evaluation process is to estimate the fraction of debris that would be transported from debris sources within containment to the sump suction strainers.

NRC Staff Review

The NRC staff review is based on documentation provided by the licensee through December 18, 2013, as supplemented by the December 1, 2016, submittal. The guidance documents used by the NRC staff for the review include the content guide and RG 1.82, Revision 4.

The licensee provided a high-quality response that generally addressed the information requested in the content guide. The NRC staff had several questions about the details of the transport calculation performed for Palo Verde that were not clearly explained, but due to the weight of the conservatisms in the analysis, the NRC staff determined that no RAIs were necessary in review of debris transport.

The licensee's evaluation quantifies the debris that would be transported to the ECCS sump strainers. The amount of debris generated and its characteristics (density) are used to determine debris transport and strainer loading. The debris loading is maximized to conservatively evaluate the blockage of the strainers and its effects. The time dependent loading of debris on the strainers is not credited to reduce the effect of any strainer blockage early in the accident recovery.

The licensee's analysis followed guidance from the NRC staff GR/SE and RG 1.82. The licensee addressed the four major debris transport modes from the guidance documents: blowdown, washdown, pool fill-up, and recirculation. A summary of each transport phase is discussed briefly below.

- Blowdown (horizontal and vertical transport of debris by the break jet): All fiber, particulate, and RMI debris is conservatively assumed to transport to the containment floor, and no debris is transported upwards to the containment dome.

- Washdown (vertical transport of debris by the containment sprays (CS)/break flow): All fiber, particulate, and RMI debris is conservatively assumed to transport to the containment floor during blowdown. Thus, there is no washdown transport modeled.

- Pool Fill-Up (horizontal transport of the debris by break and CS flows to active and inactive areas of the containment pool): All fiber, particulate, and RMI debris is conservatively assumed to transport out of the SG D-rings to the containment pool (an active area). Thus, there is no pool fill-up transport modeled.

- Recirculation (horizontal transport of the debris in the active areas of the containment pool by the recirculation flow through the ECCS/CSS): A recirculation transport analysis was performed using a computational fluid dynamics (CFD) model of the post-LOCA recirculation flow patterns in containment. Velocity contours from this analysis are used to determine whether each debris type will stall or transport to the ECCS sump strainers.

The majority of the debris transport section focused on recirculation transport and the supplemental CFD analysis. The steady-state CFD analysis was performed using FLUENT Version 6.1.22 software. The flow patterns and velocities attained from this analysis are then used as inputs to the debris transport analysis.

The CFD analysis considered five LOCA scenarios shown in the table below.

LOCA Scenarios Simulated

Scenario #	Break Flow Rate ([gallons per minute] gp	Break Entry Point	Sump(s) Operating	Containment Spray Flow (gpm)
1	1,400	Southeast stairwell	Southeast	4,885
2	2,800	Southeast stairwell	Southeast & Southwest	9,770
3	1,400	Southwest SG D-ring opening	Southwest	4,885
4	1,400	Northwest SG D-ring opening	Southwest	4,885
5	12,800	Northwest SG D-ring opening	Southeast & Southwest	10,400

Flow patterns were derived for the five LOCA scenarios. The table below provides the highest continuous velocity (from the break to the sump) found in the CFD analyses for the analyzed LOCA scenarios. These continuous velocities are then compared against the required tumbling velocity (transport threshold velocity) and lift over curb velocities (velocity required to transport the specific debris from the containment floor to the ECCS sump strainer) for each debris type.

Highest Continuous Velocity Connecting Break to Sump Region

	Scenario				
	1	2	3	4	5
Highest continuous velocity zone connecting the break to the sump region feet per second (ft/sec)	0.13	0.21	0.17	0.10	0.64

The licensee's transport analysis found that large RMI, fibrous debris, equipment labels, and degraded qualified epoxy coating chips do not transport to the sump for CFD Scenarios 1 through 4. For CFD Scenario 5, large RMI, equipment labels, glass lighting and degraded qualified epoxy coating chips do not transport to the sump, but large piece fibrous debris does transport to the sump. Accordingly, the Scenario 5 results are used to determine the bounding debris load at the strainer.

No debris interceptors are installed or credited in the analysis. However, there is a curb around the perimeter of each ECCS sump strainer, which does inhibit the transfer of debris to the strainer. All small fines debris, regardless of type, was modeled as transporting to the ECCS sump strainer (i.e., no credit was taken for settling of small fines). This is conservative and acceptable with respect to approved methods.

The calculated debris transport fractions and the total quantities of each type of debris transported to the strainers were determined and are summarized in the table below for the bounding break.

Bounding Debris Quantity at Sump for Primary Loop Break

Debris Type	Units	Fraction of Debris at Sump Screen	Debris Generated	Debris Quantity at Sump
Insulation within Break ZOI				
Stainless Steel Mirror RMI Foil	[ft^2]	0.050	23,166	1,158
Stainless Steel Transco RMI Foil	[ft^2]	0.050	30,877	1,544
Nukon	[ft^3]	1.00	9.82	9.82
Nukon (fines/small pieces)	[ft^3]	1.00	5.89	5.89
Nukon (large pieces)	[ft^3]	1.00	3.93	3.93
Thermo-Lag 330	[ft^3]	1.00	3.53	3.53
Alpha-cloth	[ft^3]	1.00	0.1	0.1
RTV 738 Sealant	[ft^3]	1.00	0.020	0.020
Qualified Coatings				
Steel Coatings Inorganic Zinc (IOZ)	[ft^3]	1.00	4.0	4.0
Concrete Coatings (Epoxy)	[ft^3]	1.00	0.5	0.5
Unqualified Coatings (Fail as Chips)				
Epoxy	[ft^2]	0	5532	0.0
Epoxy Concrete 3-Coat Floors	[ft^2]	0	802	0.0
Unqualified Coatings (Fail as Particulates)				
Appurtenances Epoxy	[ft^3]	1.00	0.072	0.072
IOZ	[ft^3]	1.00	1.141	1.141
Cold Galvanizing Compound (ZRC)	[ft^3]	1.00	0.095	0.095
Alkyd Enamel	[ft^3]	1.00	0.224	0.224
Epoxy Concrete Sealer	[ft^3]	1.00	3.40	3.40
Foreign Materials				
Total Foreign Materials	[ft^2]	0.195	449.55	87.58

Plastic Labels	[ft^2]	0	181.14	0
Metallic Labels	[ft^2]	0	41.63	0
Glass Lighting	[ft^2]	0	139.2	0
Other Foreign Materials	[ft^2]	1.00	87.58	87.58
Latent Debris				
Latent Debris (Particulates)	[lbs]	1.00	170	170
Latent Debris (Fiber)	[lbs]	1.00	30	30

The NRC staff found the following conservatisms used in the debris transport calculations:

- For debris transport, the analysis assumed run-out flow from the CS, low-pressure safety injection (LPSI) and high-pressure safety injection (HPSI) systems. In fact, the LPSI pumps are not expected to be operating post-switchover, and if they are operating, then the spray pumps would be secured. Furthermore, rather than computing flows based upon actual system operating conditions, all of the pumps were assumed to be operating at run-out.

- The analysis assumed that all fiber, particulate, and RMI debris from the analyzed breaks during blowdown, washdown, and pool fill-up are transported to an active area of the containment pool.

- The analysis assumed no credit for inactive pool volumes.

- The analysis assumed the highest continuous bulk velocity between the break entry point and the sump as the means of determining transport to the sump strainers.

- The analysis assumed complete transport for the entirety of the 60 percent of fibrous debris that was considered to be in the small-fines category, per the conservative baseline guidance.

- The analysis assumed complete transport of small fines debris.

There were some potential shortcomings in the recirculation transport CFD model. The most important information that was not provided to the NRC staff was whether the model used one or two trains running to determine the velocities in the recirculation pool. However, the NRC staff was able to determine that the debris types and sizes that are important to head loss were all predicted to transport to the strainer. Therefore, the velocity used is not important to the ultimate evaluation. Thus, the NRC staff considers the Palo Verde transport calculation to be technically defensible and to be conservative overall rather than best-estimate.

On December 1, 2016, the licensee provided a supplemental response (addendum) to address the newly discovered Microtherm, Temp-Mat, and Nukon insulation, which were discovered in April 2015, spring 2016, and fall 2015, respectively. The results from the addendum are added to the results from the original evaluation discussed above in this section.

The licensee considered three flow scenarios for each of the three break location cases above:

- Flow Scenario 5 at which LPSI is not secured after the recirculation actuation signal (resulting in 70 percent of total recirculation flow)

- Flow Scenario 5 at which LPSI is secured after recirculation actuation signal (resulting in 30 percent of total recirculation flow)

- Flow scenarios where only a single train operates with HPSI, LPSI, and CS operating during injection, and one HPSI and one CS pump operate taking suction from the sump after the initiation of recirculation.

The licensee stated that a complete description of a debris generation and debris transport analysis case was achieved by a combination of the above location cases and flow scenario case descriptions.

The licensee summarized in Table 4-4 of its December 1, 2016, submittal, the debris generation and debris transport analysis cases, and their associated recirculation flow, that are considered in assessment of the Microtherm and Temp-Mat insulation discovered after its initial analysis was completed. The NRC staff notes that the values of 16,600 gpm in Table 4-4 are typos and should be 11,600 gpm. The analyses were performed using 11,600 gpm.

The analysis in the addendum considers limited transport of Temp-Mat from the reactor cavity based on refined size distribution and CFD-based turbulent kinetic energy estimates that show only fine Temp-Mat is able to transport. All Microtherm generated is assumed to be fine and it is all assumed to transport to the strainers.

The licensee provided flowpath and fibrous debris transport fractions for the D-ring SG sub-compartment breaks and the RPV nozzle breaks. Table 4-8 of the addendum submittal, contains the total transport fractions from the reactor cavity. Table 4-9 of the addendum submittal contains the Temp-Mat debris transport results. The NRC staff notes that the Temp-Mat fines in this table include fines from erosion of all non-transporting small and large pieces of Temp-Mat associated with RPV nozzle break cases. Table 4-10 of the addendum submittal contains the total fiber transport results. The NRC staff notes the fiber quantities in this table take into account that every cubic foot of Temp-Mat is equivalent to 4.92 ft^3 of Nukon. This can be illustrated by multiplying the transported Temp-Mat fines value in the last row of Table 4-9 (2.5 ft^3) by 4.92, resulting in 12.1 ft^3, as shown in the last row of Table 4-10.

Specifically, the licensee provided Temp-Mat debris transport results and total fiber transport results. The licensee evaluated the Temp-Mat transport results. The licensee provided multiple tables. Table 4-11 of the addendum submittal contains a summary of fiber loading from the analyses of record to the test of record. Table 4-12 of the addendum submittal provides a comparison between the total new/current fibrous debris quantities transported to the sump strainer versus the fibrous debris quantities used in the test of record strainer prototype head loss testing per the test specification.

The results of the licensee's debris transport analysis show that the total fiber associated with all breaks for the configuration after planned Temp-Mat removal is less than the total fiber used in the test of record.

The quantity of fines/smalls associated with the configuration after planned Temp-Mat removal, is less than or within 19 percent of the total fiber used in the test of record. Because two cases were determined to transport more fiber to the strainer than was included in the licensee's test program, justification for this case is required. The evaluation of the fiber amount from this case is discussed in the head loss section.

The licensee also calculated a Microtherm debris term at the strainer that exceeds the amount of Microtherm included in its test program. The original evaluation had zero Microtherm transported to the strainer. Because the quantity of Microtherm is greater than the amount tested, it is also evaluated. The evaluation is discussed in the head loss section.

NRC Staff Conclusion

For this review area, the licensee provided information such that the NRC staff has reasonable assurance that the debris transport has been addressed conservatively or prototypically using approved methods in the Revised Content Guide dated 2007 and Regulatory Guide 1.82. Therefore, the NRC staff concludes that the debris transport evaluation for Palo Verde is acceptable. The NRC staff considers this area closed for GL 2004-02.

8.0 HEAD LOSS AND VORTEXING

The objectives of the head loss and vortexing evaluations are to calculate head loss across the sump strainer and to evaluate the susceptibility of the strainer to vortex formation.

NRC Staff Review

The NRC staff review is based on documentation provided by the licensee through March 13, 2009, as well as the updated supplements submitted December 18, 2013, and December 1, 2016, and the final supplement response dated February 22, 2022. The guidance documents used for the review include the content guide and the GR/SE.

The licensee calculated the minimum submergence of the strainer under all small break LOCA (SBLOCA) and large break LOCA (LBLOCA) conditions. With a minimum containment flood water level of 84.5 feet, the minimum strainer submergence is 2.1 inches above the top of the strainers for Palo Verde.

The licensee used results from the clean strainer head loss test (Test 1) performed in April 2008, at the Control Components, Inc. (CCI) multi-functional test loop for evaluating vortex formation on clean strainers. The vortex testing was done at a submergence of approximately 0.4 inches (1 centimeter) with a scaled flow rate of 49,150 gpm. These testing conditions are conservative compared to the plant submergence of 2.1 inches and flow velocity of 11,600 gpm. No vortices were observed at these test conditions. Since no vortices were observed at conditions more conservative than those at the plant, the results are acceptable.

When evaluating vortex formation on debris laden strainers with a pump stop and restart, the licensee used generic tests performed at CCI with unperforated cover plates (Palo Verde strainers have unperforated cover plates). Vortexing limits from these CCI tests were compared to the actual parameter values at the plant (i.e., head loss, submergence). It was determined that vortexing does not occur for pump stop and restart after a “clean screen window” has formed on debris laden strainers.

Testing was performed for the licensee by CCI to determine head loss characteristics across the sump strainer. Small and large scale tests were performed to develop strainer sizing requirements for Palo Verde. Results of chemical effects head loss tests performed on the multi-functional test loop validated the sizing of the strainers. NRC staff witnessed the chemical effects testing in April 2008 and concluded that the test methods being employed by CCI were generally prototypic or conservative (Trip Report dated July 16, 2008 (ADAMS Accession

No. ML081640193)). While reviewing Section 3.f.4, "Performance Tests," of the December 18, 2013, supplement, the NRC staff noted the following:

- The testing arrangement of the strainer modules was conservative when compared to the plant.
- The debris quantities added to the test loop are computed based on the debris quantities in the plant with a computed scale factor.
- Testing of Nukon insulation and latent fiber, as well as Thermo-Lag 330 used the same specimens as found in the plant. No surrogates were used.
- The test loop was checked for sedimentation after each fiber addition.
- If the sedimentation was agitated, the test engineer ensured there were no indications that the debris bed was adversely or non-conservatively affected.
- Testing was conducted in accordance with NRC staff guidance.

The quantity of tested debris was compared to the analytically determined debris load at the strainer. Results are reported in Table 3-31 of the December 18, 2013, supplement. All types of insulation tested had higher quantities than were analytically determined to reach the strainer by debris generation and transport analysis. The NRC staff finds these inputs conservative.

The licensee followed NRC guidance for chemical effects and coatings testing methodology. Further discussions relating to coatings and chemical effects can be found in Sections 10 and 17, respectively of this document.

The head loss stability criterion following non-chemical and chemical debris addition was plus or minus 1 percent change for 60 continuous minutes while the stability criterion during the flow sweep was plus or minus 2 percent change for 30 continuous minutes. The licensee stated in its December 18, 2013, submittal, the following: "The strainer head loss data collected during the flow sweep included the total amount of generated debris and the 30-day chemical precipitate quantity. Therefore, stable head loss measurements during the flow sweep are indicative of the head loss which would be experienced after 30 days. Therefore, extrapolation of the test data to 30 days is not required." Although this does not fully address the test termination criteria in NRC approved guidance, the test was conducted over approximately 8 days and head loss at the end of the test was relatively stable. The licensee also demonstrated significant NPSH margin. Therefore, the NRC staff concluded that the values used for strainer head loss are adequate.

Testing at Palo Verde did not result in the formation of a thin bed due to the limited fiber quantities in the plant. The quantity of fiber fines present in the plant could result in a theoretical debris bed that is 1/11-inch thick if the fiber is distributed evenly over the strainer surfaces. This thickness is less than the generally accepted required bed thickness to experience a thin bed effect, therefore, the full debris loading is bounding. During the Palo Verde testing, the fiber did not cover the strainer uniformly and some open screen area was observed.

The clean strainer head loss from the chemical effects tests is 0.013 feet. The total clean strainer head loss includes two additional head loss contributions: redirection head loss from horizontal to vertical between the cartridges in the strainer cavities and constriction head loss through openings in the lower duct plate. The value of these two additional head loss contributions was calculated theoretically. The total head loss is the sum of all three head loss contributions yielding a result of 0.081 feet at a flow rate of 11,600 gpm (for first hour) and 0.026 feet at a flow rate of 6,600 gpm (after 1 hour). The method of combining test data and theory to calculate the total clean strainer head loss used by the licensee for Palo Verde is acceptable because industry standard methods were used for the calculation.

The licensee used a maximum sump discharge flow rate of 11,600 gpm for the first hour of recirculation mode. This is based on one LPSI pump, one CSS pump, and one HPSI pump operating at maximum flow. DBA mitigation credits only the HPSI and CSS pumps (6,600 gpm), therefore this higher flow rate is conservative. After 1 hour into the accident, a flow rate of 6,600 gpm is used based on the reduction of flow that occurs when the running LPSI pump is tripped. This assumes it will take 1 hour for operators to trip the LPSI pump, which is conservative because Palo Verde has a procedure to ensure that a LPSI pump that fails to automatically trip is secured as soon as possible.

Because the test conditions are different than those at the plant, the measured head loss was adjusted accounting for temperature, flow rate, viscosity, and chemical effects resulting in a baseline head loss calculation of 4.58 feet. The NRC staff finds this adjustment acceptable because it was performed using NRC staff approved methods.

After the 2008 testing was conducted, a change in guidance relating to the ZOI for IOZ coatings, discovery of additional coating material in containment, and reevaluation of unqualified coatings led to an increase in the particulate debris load at Palo Verde. An analytical approach to determine the design basis head loss, including the additional debris, was employed. Part of this approach uses the NUREG/CR-6224 correlation. The licensee specifies that the correlation was used to determine a bump-up factor for the base (tested) head loss, but not the design basis (adjusted) head loss. Additionally, this bump-up factor was applied to the head loss components of the strainer structure, the open and debris laden strainer area, and the chemical precipitate portion of the debris bed when in reality it would only apply to the non-chemical debris laden portion of the strainer. Due to these conservatisms, the use of the correlation for this evaluation is acceptable. The results of the additional debris load are reported in Tables 3-38c, "Design Basis Strainer Head Loss Values When LPSI Fails to Trip and Remains Faulted Throughout Accident Scenario (in ft)," and 3-38d, "Design Basis Strainer Head Loss Values for Failure of a Single ECCS Train Scenario (in ft)," of the December 18, 2013, supplement. The head loss values and bump up factors are shown to vary by flow rate and temperature with the limiting head loss occurring when a LPSI pump fails to trip. The NRC staff notes that the comparison with Salem Nuclear Generating Station (Salem), Unit 2, Test 6, which is discussed below, does not cite that the Salem test contained more particulate than the limiting Palo Verde test. The comparison with the Salem test provides additional justification that the amount of particulate that may transport to the Palo Verde strainers will not result in excessive head loss.

Strainers at Palo Verde are fully submerged under all SBLOCA and LBLOCA conditions. There are two pipes and a conduit penetrating the strainer floor plates extending above the post-LOCA pool level (i.e., Containment flood water level).

These penetrations are sealed to ensure no air ingestion will occur at the penetrations. The licensee has adequately addressed strainer submergence and any possible venting cases by ensuring that there are no unsealed strainer penetrations that extend above the minimum sump water level.

No credit was taken for near field settling in head loss testing at Palo Verde. During testing, agitation was used to ensure that essentially all of the debris was transported to the strainer. Agitation, when used, employed methods that were designed to ensure that the debris bed was not disturbed.

The licensee used temperature/viscosity scaling through debris laden portions of the strainer using guidance in NUREG/CR-6224 to determine strainer head loss. The results of testing indicated that bore holes were not present, but open areas on the strainers were observed. Temperature/viscosity scaling was not applied to head loss through these open areas. The methodology used by the licensee for Palo Verde regarding temperature/viscosity scaling is found acceptable by the NRC staff because it treats the effects of viscosity on head loss realistically.

For Palo Verde, head loss exceeds the strainer submergence, so an evaluation was done to show that adequate pressure is available to prevent flashing within the debris bed. The flashing evaluation concludes that a strainer head loss of 31.8 feet is required for flashing to occur. This is much larger than the calculated debris head loss; therefore, no flashing is expected within the debris bed. Flashing is also not a concern at the pump inlet since the elevation difference between the sump outlet and pump inlet is larger than the maximum suction line loss.

The potential for deaeration was analyzed to determine whether the void fraction entering the ECCS or CSS pumps could negatively impact their operation. The methodology employed by the licensee for this analysis is consistent with NUREG/CR-6224. The maximum void fraction due to deaeration for each ECCS and CS pump is documented as 0.346 percent. The NPSH section discusses the impact of deaeration on the NPSH of ECCS and CSS pumps.

There were numerous RAIs regarding head loss and vortexing throughout the review. The December 18, 2013, supplement addressed the final two RAIs of the review. Many of the earlier RAIs were resolved during the NRC staff observation of Palo Verde strainer testing. The NRC staff evaluation of these final RAIs is as follows.

The first RAI requested that the licensee provide additional basis for concluding that the quantity of Thermo-Lag fines used in the test was representative with regard to the quantity of fines that would be expected to be generated from Thermo-Lag debris due to blowdown from a pipe rupture. The licensee justified its methodology for creating Thermo-lag debris as conservative by including excess fines in the test. The excess fines were generated by cutting instead of breaking the material, and by subjecting the material to a water jet of significantly higher pressure than the maximum jet pressure that could impinge on the material in the plant. This is also related to the debris generation area where the licensee stated that Thermo-lag is a significant distance from potential break locations and unlikely to be damaged.

The second RAI requested the licensee to reevaluate deaeration and determine any required adjustment to NPSH. A deaeration analysis was completed by the licensee. The maximum void fraction for each ECCS and CS pump is documented as 0.346 percent. The NPSH section of this summary discusses the impact of this deaeration analysis on the NPSH of ECCS and CSS pumps.

The NRC staff concludes that the licensee has sufficiently addressed all RAIs relating to head loss and vortexing.

On December 1, 2016, the licensee provided a supplemental response to address the newly discovered Microtherm, Temp-Mat, and Nukon insulation, which were discovered in April 2015, spring 2016, and fall 2015, respectively.

The licensee provided a table summarizing the current temperature-dependent structural and hydraulic capacity of the strainers. The licensee stated that the overall strainer limit at each temperature is the governing limit based on revised structural and existing NPSH limits and provided a table to demonstrate the limiting differential pressure limit at several temperatures. Above or about 194 degrees Fahrenheit (°F), the differential pressure is limited by NPSH margin. Below this temperature there is significant subcooling that provides added NPSH margin. Therefore, at lower temperatures, structural margins limit the allowable differential pressure across the strainer.

In its February 22, 2022, final supplement, the licensee provided a revised table providing the strainer structural and hydraulic capacity as a function of sump fluid temperature. The updated table reflects the revised NPSH calculation results based on the design basis strainer head loss values presented in Table 4-18, "Summary of Design Headloss, Limits and Margin," of the December 1, 2016, addendum submittal. The revised NPSH calculation documents lower minimum hydraulic limits than what was reported for some sump fluid temperatures; however, for the affected sump temperatures, the structural limit is bounding, so the overall strainer limit that was reported is unchanged.

The licensee stated its head loss testing did not include microporous insulation debris, so to justify strainer head loss in the presence of Microtherm, it used results of testing performed by Salem Unit 2.

The licensee stated for the D-ring generator sub-compartment breaks, that once the Temp-Mat removal is accomplished, all three Palo Verde Units will be restored to the condition that was described in its December 18, 2013, supplement. The licensee stated that as before, the S1 break will be the governing D-ring break, the fiber quantities associated with the S1 break will be restored to those in the analysis of record, the maximum head loss associated with D-ring breaks (which do not include any transport of Microtherm) will be restored to those documented in its previous debris transport calculation (December 2016 addendum). The reactor cavity breaks could result in transported amounts of Temp-Mat greater than that included in the Palo Verde test program. This is discussed below (RPV nozzle breaks).

For RPV nozzle breaks, the licensee stated that its head loss test of record did not address Microtherm debris or the maximum amount of fibrous debris that could be generated. Therefore, it was not possible to estimate maximum head loss with the presence of Microtherm or quantity of fiber from the RPV nozzle breaks based solely on its head loss test of record results. The licensee stated that other plants with CCI strainers conducted testing that included microporous insulation debris (e.g., Min-K and Cal-Sil) and greater amounts of fibrous debris. Particularly, testing performed by Salem included Min-K and had other debris loads that bound the debris loads from the RPV nozzle breaks with the exception of particulate debris. Therefore, the licensee provided a comparison of its RPV break head loss-related parameters for certain flow scenarios versus Salem Unit 2, Test 6. Because the Palo Verde and Salem strainers are different areas, the licensee compared debris loading on a per area basis to remove any bias due to different strainer areas. All discussion here is based on debris load per strainer area.

The licensee stated that the non-chemical and chemical debris loading for Salem Unit 2, Test 6 bound Palo Verde. The licensee also stated that the approach velocities for the Salem and Palo Verde conditions are similar, within 12 percent. The licensee also stated that Palo Verde observed open/clean strainer surface area during testing, whereas Salem Unit 2, Test 6 did not have open area. The amount of Min-K in the Salem test was slightly greater than the Palo Verde condition. The amount of particulate for the Palo Verde condition was not bounded for the case where one strainer is considered to be failed. The licensee claimed that given the significantly greater fiber and chemical loads for Salem Unit 2, Test 6, the head losses for Salem Unit 2, Test 6, are greater than those that would occur for Palo Verde. The licensee considered several flow cases for Palo Verde including the design basis single train case and the cases for the individual strainers where one LPSI pump fails to trip at the initiation of recirculation.

The licensee stated that because there is no reliable method for estimating the amount by which Salem Unit 2, Test 6 head loss exceeds the head loss for the Palo Verde conditions, the Salem Unit 2, Test 6 head loss is assigned as the new design head loss value for Palo Verde.

The licensee also determined that at higher temperatures, the Palo Verde test results provided more limiting head loss values. This occurs due to the temperature/viscosity extrapolation methods that were used for the Palo Verde test due to open strainer area and due to higher flow rates that occur if a LPSI pump fails to trip at the initiation of recirculation. For the higher temperatures, the licensee used the more conservative head loss values derived from the Palo Verde testing. The Palo Verde analysis also assumed that chemical effects were present at all times while Salem assumed that chemical precipitates would not form above 160 °F.

The licensee stated that the density of Temp-Mat is 11.8 lb/ft^3 and Nukon is 2.4 lb/ft^3 (Temp-Mat is approximately 5 times as dense as Nukon). The licensee stated that when estimating total mass of generated or transported fiber, this difference in density is taken into account.

The licensee considered all of the evaluated debris loading conditions for Palo Verde and calculated that the theoretical fiber bed thickness for all cases is less than 1/16 inch. The licensee noted that this meets the clean plant criteria for fiber but recognized that the clean plant criteria is not applicable in cases where problematic debris is present.

The licensee stated that there is no potential for formation of vortices in the event of pump stopping and restarting or flashing downstream of the sump strainer in the current design configuration. The licensee also stated that deaeration will not result in operational issues over the temperature range of interest for the configuration that results after removal of the insulation described in Table 3.1 of its December 1, 2016, submittal.

The NRC considers Min-K and Microtherm to have similar head loss properties. Therefore, the comparison of the Salem head loss test, that used Min-K, is appropriate to compare to the Palo Verde case which includes Microtherm.

The NRC staff concluded that the licensee used an appropriate density correction for Temp-Mat to Nukon.

The licensee provided considerable discussion for the case when a failure of LPSI to trip occurs. For this case, there is still one train in service with normal flow through the strainer. This train is assumed to continue to operate normally.

Therefore, the strainer with the high flow is not considered significant and the strainer with the lower flow will operate as analyzed. The only problem that could occur with the high flow train is that the strainer could fail structurally and allow significant bypass. The licensee has demonstrated that they can secure the LPSI pump within an hour. Within this time, the fluid temperature is high, chemicals would not be present, and all debris may not have transported to the strainer. These factors maintain the differential pressure well below the structural limit. Therefore, the NRC staff concluded that there is reasonable assurance that the LPSI failure to trip case would not result in any safety consequences to Palo Verde.

The NRC staff evaluated the analysis that compared the Palo Verde plant conditions with the Salem test conditions. The NRC staff concluded that the referenced Salem test was bounding of the Palo Verde plant conditions for most parameters. However, some parameters were not bounded. These are discussed below.

The velocity in the Salem test was lower than the Palo Verde design basis condition. The licensee stated that the Palo Verde design basis flow rate is 112 percent of the Salem test condition. The lower flow rate during the test would result in a lower head loss and is therefore non-conservative. The NRC staff concluded that the lower test flow rate was acceptable for three reasons. First, the test contained much greater fibrous debris amounts and conservative amounts problematic debris and chemical precipitates. Second, Palo Verde maintains significant NPSH margins and somewhat lower, but still substantial margins to structural limits. Third, the licensee used conservative assumptions throughout the analysis and demonstrated that the fiber loading on the strainer is very small indicating that open strainer area will remain, even under the most severe fiber loading conditions.

Also, with respect to the difference in velocity, the NRC staff noted that the Palo Verde assumption for sacrificial strainer area during testing was significantly conservative. Instead of using 75 ft^2 as allowed by guidance, the analysis assumed 400 ft^2. Adding 325 ft^2 to the total strainer area would decrease the velocity through the strainer for the design basis case to a value essentially the same as the Salem test value. This reduces the significance of the lower flow velocity that was present in the Salem test. This also further reduces the debris load per strainer area for the Palo Verde cases. The NRC staff recognizes that the licensee desires to maintain conservatism in the sacrificial strainer area, but also notes that it skews the inputs and results of the evaluation in the conservative direction.

The particulate amounts in the Salem test were lower than those that may occur in the plant at Palo Verde. Then NRC staff recognizes that the coating source terms are generally calculated very conservatively. In this case, Palo Verde assumed that all of the non-epoxy unqualified coatings, and a bounding amount of qualified coatings would transport to the strainer. This is conservative. As stated above, using a more realistic strainer area would reduce the particulate load per strainer area resulting in a better correlation between the Salem test load and the Palo Verde plant condition. The NRC staff also considered that the chemical loading per strainer area was significantly greater in the Salem test than predicted for Palo Verde. These conservatisms in the test provide adequate assurance that the Salem test provides an acceptable head loss for Palo Verde, even though the particulate loading was lower in the test.

In addition to the above, the NRC staff noted the following regarding the Palo Verde analysis. The licensee demonstrated that the plant meets the clean plant criteria for fiber bed thickness. The NRC staff notes that this is not allowed as a resolution path for plants with problematic insulation materials in containment but shows that the fiber amounts at Palo Verde are very low.

The NRC staff concluded that it is likely that Palo Verde will maintain open strainer area throughout any LOCA recovery period.

The NRC staff concluded that there would be no change to the licensee's vortexing or flashing evaluations, and that any changes to the deaeration values would be insignificant. The licensee used conservative assumptions throughout the evaluation. Therefore, the NRC staff accepts the licensee's comparative analysis for the Salem head loss test and the Palo Verde plant condition as a valid methodology.

NRC Staff Conclusion

Based on the test results provided by the licensee, the NRC staff concluded that the head loss portion of the analysis has been completed adequately. Testing and analysis was conducted using approved guidance in the content guide or alternate methods determined acceptable by the NRC staff. The other information provided by the licensee, either previously or in the recent submittals, provide adequate documentation that the strainer will perform its function during any required recirculation operation at Palo Verde.

For this review area, the licensee has provided information such that the NRC staff has reasonable assurance that the subject review area has overall been addressed conservatively or prototypically. Therefore, the NRC staff concludes that the head loss and vortexing evaluation for Palo Verde is acceptable. The NRC staff considers this item closed for GL 2004-02.

9.0 NET POSITIVE SUCTION HEAD

The objective of the NPSH section is to calculate the respective NPSH margins for the ECCS and CSS pumps that would exist during a LOCA, considering a spectrum of break sizes.

NRC Staff Review

The NRC staff review is based on documentation provided by the licensee through December 18, 2013. The guidance documents used for the review include the content guide and RG 1.82. The licensee's addendum submitted on December 1, 2016, was also reviewed.

The licensee presented a summary of its NPSH analyses. The discussion of the methodology, and the assumptions and parameters in the NPSH analyses was clear. Each of the technical issues specified in the content guide was addressed by the licensee. Detail concerning the parameters, assumptions, and conservatisms in the NPSH and minimum flood level analyses was presented. The methodology used was standard industry practice for the calculation of NPSH margin. The NPSH analyses were performed with conservative and realistic assumptions.

The licensee used the maximum ECCS pump flow rates in the Palo Verde sump recirculation NPSH calculations for both LBLOCA and SBLOCA accidents. As discussed in the head loss and vortexing analysis, Palo Verde uses a maximum sump discharge flow rate of 11,600 gpm for the first hour of recirculation mode. This is based on one LPSI pump, one CSS pump, and one HPSI pump operating at maximum flow. DBA mitigation credits only the HPSI and CSS pumps, therefore using higher flow rate to include LPSI is conservative.

After 1 hour into the accident, a flow rate of 6,600 gpm is used because operators would have time to secure a LPSI pump if it failed to automatically trip at the start of recirculation. The 1-hour time for operators to trip the LPSI pump is conservative based on industry evaluations. The licensee states that the ECCS sump water temperature profile provides a peak temperature of 238.6 °F. The sump water temperature used in the NPSH analyses ranges from 77 °F to 252 °F. The minimum containment water level is at an elevation of 84 feet 6 inches. The elevation corresponds to all strainers being submerged a minimum of 2.1 inches during recirculation.

A number of assumptions used in the calculations for the ECCS and CSS flow rates, both for LBLOCA and SBLOCA, were given. Conservative modeling techniques and design inputs listed below were used to provide bounding results. These included the following:

- The determination of recirculation flow rate assumes maximum flow of the operating pumps.
- The containment response for determination of the sump temperature profile assumes loss of offsite power coincident with a LOCA.
- The most severe single active failure is hypothesized as loss of a CS pump.
- For determining a minimum containment water level, assumptions were selected to minimize available water to the sump via various hold up mechanisms and limiting break locations.

In the December 18, 2013, supplemental response, the required NPSH values for the pumps were calculated by using the maximum flow rate from the vendor for the Palo Verde ECCS and CSS pumps. Deaeration for each pump (i.e., LPSI, HPSI, CS) was accounted for by increasing the NPSH required by a factor specified by the void fraction volume percentage calculated in Section 3.f.14 of the December 18, 2013 supplement. The increase in NPSH required due to deaeration ranged from 1.0 to 1.2 feet depending on the type of ECCS pump. The NRC staff calculated NPSH required values including the effects of the void fractions reported by the licensee in its 2013 submittal. The NRC staff calculations showed that the NPSH required values would increase by 3 to 4 feet if all conservative assumptions regarding head loss, flow rates, sump temperature, and timing were imposed simultaneously. In its December 1, 2016, submittal the licensee stated that the pump submergence is greater than the strainer head loss so that any deaeration would be reversed by the time the fluid reaches the pump suction. The NRC staff agrees that reversal of the deaeration will occur but has no information regarding the time required for gas reabsorption or the time required for the fluid to transport from the strainer to the pump suction. The NRC staff allows credit for the collapse of gas bubbles as they transport to the pump suction, but not the reabsorption of gases into the fluid. The NRC staff determined that the limiting head loss assumed by the licensee in its void fraction calculation was about double that, which could reasonably be expected to occur. This results in a significant increase in predicted deaeration. The licensee did not credit containment pressure in its calculation, which would reduce or eliminate deaeration of the fluid depending on the pressure assumed. The NRC staff also considered that the pumps taking suction from the containment sump have significant NPSH margin that is very unlikely to be eliminated by voids at the pump suction, and that the NPSH margin calculation is performed conservatively. Therefore, the NRC staff concludes that entrained gas at the pump suctions will not result in adverse effects on the pumps.

The licensee described the system response scenarios for LBLOCA and SBLOCAs, and the operational status for each ECCS and CSS pump before and after the initiation of recirculation. When a LOCA occurs, the SI and CS systems are automatically actuated during a sequence of events. This initiates operation of the LPSI, HPSI, and CSS pumps. Suction for these pumps comes from the RWT until a low level setpoint is reached in the RWT. Suction is then switched to the ECCS sump.

The licensee evaluated two independent failure modes in the head loss evaluations. The first is the loss of one ECCS/CSS train. In this mode, HPSI and CSS pumps are supplied by the non-faulted sump and the LPSI pump trips as it is supposed to. The second is the failure of a LPSI pump to trip. In this mode, the HPSI, CSS, and LPSI pumps are supplied by the sump in that train.

The containment post-LOCA water level was determined by considering the volumes occupied by structures and the cavity volumes inside the containment that are available to collect water for recirculation to the minimum volume of water discharged during the event. The licensee made various assumptions when calculating minimum water level in the NPSH calculation. Phenomena that could reduce the water contribution to the containment sump were taken into account when determining the minimum water level in the containment. The assumptions used by the licensee are realistic and conservative and, therefore, acceptable to the NRC staff.

The sources of water and the contributions of each source to the minimum water volume in containment were provided. The sources credited were as follows:

Water Source	Volume
RWT Volume	72,326 ft^3 / 541,000 gallons
RCS Volume Spill	3,364 ft^3 / 25,164 gallons (LBLOCA only)
Four SI Tanks	1,750 ft^3 / 13,091 gallons each (LBLOCA only)

The minimum water transferred from the RWT during injection is ensured by RWT volume controls and specified in the technical specifications. As documented in the table above, the minimum water inventory that will be transferred is 72,326 ft^3 or 541,000 gallons during the limiting SBLOCA. This amount of inventory was also used when computing NPSH following a LBLOCA to be conservative. For the SBLOCA, the strainers would remain submerged by a minimum of 2.1 inches. For large breaks, the RCS volume spill and SI tanks will add to the inventory provided by the RWT.

To assure adequate inventory to fully submerge the strainers, the licensee submitted a license amendment request to increase the minimum technical specification level in the RWT. This request was granted and results in the minimum submergence discussed above.

The licensee used a temperature of 193.8 °F when calculating the minimum design NPSH margin for all pumps taking suction from the sump during recirculation mode. This temperature was used because it is the temperature at which the vapor pressure of water is equal to the minimum initial partial pressure of air in containment.

The minimum design basis NPSH margin for each pump during recirculation at Palo Verde is as follows:

Pump	NPSH Margin
HPSI Train A	3.8 feet
HPSI Train B	4.2 feet
LPSI Train A	6.3 feet
LPSI Train B	6.5 feet
CS Train A	2.9 feet
CS Train B	3.2 feet

The licensee identified the following conservatisms used in the NPSH calculations:

- Using the strainer head loss when a LPSI fails to trip instead of when one ECCS train fails to determine NPSH. This results in a 1.8 ft. conservatism for strainer head loss, and 2.7 ft. of conservatism in pump suction piping for the limiting pump (CS Train A).

- Maximum pump flow rates were used in the analyses of the pump suction head loss and the NPSH.

- Using the minimum containment flood level corresponding to a SBLOCA and the maximum strainer head loss of a LBLOCA.

- The licensee minimized the volumes of the various sources of water and maximized the mechanisms and volumes for water entrapment when calculating sump level. Therefore, the sump level was conservatively minimized.

The NRC staff concluded that the licensee NPSH evaluation contains significant conservatism and that ECCS and CSS pump NPSH margins will not be challenged by debris.

The NRC staff reviewed the licensee's addendum submittal, dated December 1, 2016, and determined that the NPSH margins for the ECCS and CSS pumps were not challenged by the new material identified in containment. At high temperatures, the Palo Verde test of record remains bounding because the Salem test did not apply chemical head loss until the sump temperature decreases to 160 °F. The Palo Verde test results conservatively apply chemical head losses at all temperatures resulting in higher head loss at temperatures above 160 °F. The licensee applied the higher head loss from the two tests at each temperature to ensure a bounding head loss was used for each case. In general, the original Palo Verde test results remain limiting for NPSH margin and the Salem test result that were applied to the newly discovered material in containment are limiting for structural margin. This is because structural margin becomes limiting at lower temperatures.

The NRC requested that the licensee provide additional information regarding the effects of deaeration on pump NPSH required. The deaeration evaluation was completed by the licensee as part of the December 18, 2013, submittal due to an RAI asked in the 2009 supplement. As discussed in the NRC staff review above, the NRC concluded that it was reasonable to assume that deaeration increased NPSH between 1.0 and 1.2 feet depending on the pump being evaluated. The NRC staff reviewed the results and concluded that NPSH margins would not be challenged by the deaeration that may occur.

NRC Staff Conclusion

For the NPSH area, the licensee provided information such that the NRC staff has reasonable assurance that it has been addressed conservatively or prototypically. Therefore, the NRC staff concludes that the NPSH evaluation for Palo Verde is acceptable when compared to the staff approved methods and guidance in the Revised Content Guide dated November 2007. The NRC staff considers this area closed for GL 2004-02.

10.0 COATINGS EVALUATION

The objective of the coatings evaluation section is to determine the plant-specific ZOI and debris characteristics for coatings for use in determining the eventual contribution of coatings to overall head loss at the sump screen.

NRC Staff Review

The NRC staff review is based on documentation provided by the licensee in its supplement dated December 18, 2013.

The ZOI for qualified epoxy coatings was 4D based on WCAP-16568-P, "Jet Impingement Testing to Determine the Zone of Influence (ZOI) for DBA-Qualified/Acceptable Coatings" (ADAMS Accession No. ML061990594; not publicly available, proprietary information). The ZOI used by the licensee for qualified IOZ coatings was 10D, which was based on the GR/SE. Coatings in the ZOI and all unqualified coatings in containment failed as fine particulate to maximize transport.

The degraded qualified epoxy coatings all fail as chips with a size greater than 1/32 of an inch. This is based on the Keeler & Long Report No. 06-0413, dated April 13, 2006 (ADAMS Accession No. ML070230390). The licensee used this approach to reduce the amount of coatings transported to the strainer. This is consistent with NRC staff guidance for this type of coating and is acceptable to the NRC staff.

In the head loss testing, a 1/11 of an inch bed was formed. The licensee performed head loss testing with the debris of coatings modeled first as particulate and again as chips. From the review guidance, if there is a thin bed present, all coating debris should be treated as particulate and transport to the sump. If there is no thin bed formed, then paint chips should be used in testing. Therefore, since the licensee performed the testing both ways, the surrogate material used for testing is acceptable to the NRC staff.

The licensee's coating assessment program is acceptable to the NRC staff since the licensee's assessment is conducted during each refueling outage, is conducted by qualified personnel, and if degraded coatings are identified, these areas are documented, and additional tests and remediation will be performed.

NRC Staff Conclusion

For this review area, the licensee provided information such that the NRC staff has reasonable assurance that the subject review area has overall been addressed conservatively or prototypically. Therefore, the NRC staff concludes that the coatings evaluation for Palo Verde is acceptable. The NRC staff considers this item closed for GL 2004-02.

11.0 DEBRIS SOURCE TERM

The objective of the debris source term section is to identify any significant design and operational measures taken to control or reduce the plant debris source term to prevent potential adverse effects on the ECCS and CSS recirculation functions.

NRC Staff Review

The NRC staff review is based on documentation provided by the licensee through December 18, 2013. The guidance documents used for the review include the content guide and RG 1.82.

The licensee has modified and implemented programmatic controls, which will control potential sources of debris introduced into containment (e.g., insulations, and foreign materials), in particular the following:

- The licensee identified the technical requirements to control the temporary installation of maintenance and monitoring equipment or transient materials in containment. Review of transient materials in containment by engineering is required.

- The licensee has a surveillance to verify cleanliness of the containment prior to establishing containment integrity. The intent of the inspection is to verify that there is no loose material that could be transported to the sump strainers during LOCA conditions. An inspection is performed once daily in affected areas of containment during outages, and an inspection of the entire containment is performed during the final entry after establishing containment integrity.

- The programs are intended to control the amount of loose materials that can be transported to the ECCS sump under LOCA conditions and ensure that any loose materials that may be transported to the sump screens does not damage the ECCS related components.

The licensee performs a containment cleanliness inspection prior to entering Mode 4 during each refueling outage. In addition, the licensee assigns a manager to inspect each area of containment during the outage to maintain cleanliness to the extent practical during outages.

The amount of latent debris was determined by sampling and statistical analysis in all three units. The maximum quantity of latent debris was determined to be 119 lbs. All latent debris is assumed to transport. The strainer design specification and related head loss testing used an assumed latent debris quantity of 200 lbs to ensure margin.

The design inputs requirements checklist of the Palo Verde design change procedure establishes controls such that no large volumetric items are added or deleted in containment that could affect the water level to free volume relationship (tank curve) of containment or LOCA flood level. In addition, the design inputs requirements checklist also requires an evaluation if the change affects the velocity of water to the ECCS sump strainers, blockage of fluid, sump level, ECCS sump post-LOCA debris, ECCS sump post-LOCA recirculation fluid chemistry, high-energy piping in the vicinity of the ECCS sump strainer, or high-energy piping outside the bioshield wall.

The licensee removed Fiberfrax insulation from the containment building secondary shield wall pipe penetrations in all three units at Palo Verde. Additionally, Nukon was removed from the letdown delay coils and microporous insulation was removed from the reactor heads. These modifications were made to reduce the potential debris source term.

The Palo Verde coatings program defines the criteria to ensure coating systems are properly applied and maintained so that the coatings perform their intended function. Inspections are an integral part of coatings application project. The program includes measures to ensure that inspections and verifications are adequate to achieve the required quality. In addition, the licensee tracks the amounts of various coatings installed within containment. Coatings added within containment are evaluated by engineering.

The NRC staff requested that the licensee describe how the containment cleanliness and foreign material exclusion programs assure that latent debris in containment will be controlled, monitored, and maintained below the amounts and characterization assumed in the ECCS strainer design.

The licensee stated that the latent debris walkdowns showed a maximum of 119 lbs. of latent debris based on surveys of all three units at Palo Verde. In addition, the licensee assumed 200 lbs of latent debris in the head loss evaluation and assumed that 15 percent of this was fiber. Both of these assumptions are conservative with respect to the plant condition. The NRC staff has evaluated the licensee's response to the RAI and has determined that the control of long-term quantity of latent debris at Palo Verde is acceptable.

NRC Staff Conclusion

For this review area, the licensee has provided information such that the NRC staff has reasonable assurance that the subject review area has been addressed conservatively or prototypically. The licensee has provided information necessary for the NRC staff to conclude that the debris source term is controlled to an acceptable level such that the recirculation function will not be adversely affected. Therefore, the NRC staff concludes that the debris source term evaluation for Palo Verde is acceptable. The NRC staff considers this item closed for GL 2004-02.

12.0 SCREEN MODIFICATION PACKAGE

The objective of the screen modification package section is to provide a basic description of the sump screen modification.

The NRC staff review is based on documentation provided by the licensee through February 29, 2008.

NRC Staff Review

The licensee provided a brief but concise description of the two 3,142 ft^2 "pocket strainers" installed in each unit. A schematic drawing of the strainer was provided. The perforation size was specified as having a 0.083 inch diameter.

Two sumps are included in the Palo Verde design, each sump serves one train of ECCS and CSS pumps. The sumps are in separate depressions in the containment floor. The sumps are located at the lowest practical elevation in containment, below the floor at elevation 80 feet.

There is a 3-inch curb around each sump that impedes large from reaching the strainers. The curb also provides protection from surface drains. No drains from upper regions impinge on the screen assemblies.

There is no significant physical barrier between the strainers above the floor, but the distance between them is 26 feet. There are no high energy pipe lines in the vicinity of the sumps or screens. Therefore, pipe whip and impinging jets are not issues to be considered. The screen is fabricated from austenitic stainless steel and zinc-coated carbon steel.

There is a cover over the strainer modules which allows the strainers to vent as the sump level increases.

The strainer configuration is designed with an access manhole in the new stainless steel floor that supports the strainer modules to allow personnel access to inspect the valves, piping, and vortex breakers within the sumps.

The new strainers are of advanced passive design using a complex geometry to increase the surface area and encourage non-uniform debris deposition on the strainer. The strainer consists of horizontal cassette pockets made of perforated plate. The strainer modules resemble “pigeon holes” or rectangular pockets which greatly increase the effective area on a limited floor footprint. Each pocket is approximately 3 inches wide by 5 inches high. With the horizontal cassette pocket (specialty) design, the strainers consist of both vertical and horizontal flow path through the screening elements.

To install the new sump strainer floor and strainer module cartridges, the containment sump temperature element, associated conduit, and the sump access ladder were relocated.

NRC Staff Conclusion

For the screen modification package review area, the licensee provided information, which confirms the NRC staff confidence that the modifications are consistent with the evaluations for ECCS strainer function provided by the licensee in other areas of the response. The information provided is as requested in the Revised Content Guide dated November 2007. Therefore, the NRC staff concludes that the sump screen modification evaluation for Palo Verde is acceptable. The NRC staff considers this item closed for GL 2004-02.

13.0 SUMP STRUCTURAL ANALYSIS

The objective of the sump structural analysis section is to verify the structural adequacy of the sump strainer including seismic loads and loads due to differential pressure, missiles, and jet forces.

NRC Staff Review

The NRC staff review of Section 3k, “Sump Structural Analysis,” of the licensee’s December 18, 2013 submittal, as supplemented by the December 1, 2016 submittal, has led to the conclusion that the licensee has adequately addressed the information requested by the content guide for GL 2004-02 Item 2(d)(vii).

The licensee stated that the replacement strainers and the associated structural support frame meet the applicable, allowable stress requirements of the American Institute of Steel Construction (AISC) Manual of Steel Construction, 9th Edition; the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (B&PVC), Subsection NF; and the American Iron and Steel Institute (AISI) manual considerations for thin sheet metal. In the submittal, the licensee stated that the strainer components were evaluated for the load combinations in the Palo Verde Updated Final Safety Analysis Report (UFSAR) and the governing load combination considered dead load, differential pressure, thermally induced stresses, and seismic loads (including hydrodynamic mass and sloshing). The governing load combination for the supporting frame was comprised of dead and seismic loads (including hydrodynamic mass and sloshing). All induced member stresses were stated to be within the allowable stress limits of the appropriate guidance documents. The maximum interaction ratio was determined to be associated with the anchor plate and was 1.567. This is less than the allowable of 1.7 (1.0 X allowable stress increase factor of 1.7).

The licensee also stated that the strainers are located outside of the bio-shield wall and are in locations that are remote to HELBs. Therefore, the strainer is not exposed to dynamic effects such as pipe whip, jet impingement, or missiles associated with a HELB. The licensee further stated that the strainer does not have backflushing capability.

The information provided by the licensee shows that the sump structural evaluation contains inherent conservatism by complying with plant guidance and accepted design standards (e.g., AISC 9th Edition, ASME B&PVC, AISI). The licensee stated that the interaction ratios all remained below 1.0, or below the allowed increased limit of 1.7. In addition, the licensee has stated that the strainers are not exposed to dynamic effects and are not designed for backflushing.

On December 1, 2016, the licensee provided a supplemental response to address the newly discovered Microtherm, Temp-Mat, and Nukon insulation, which were discovered in April 2015, spring 2016, and fall 2015, respectively.

Based on the newly discovered insulation, the licensee revised information regarding the structural integrity of the trash racks and sump screens as related to the sump strainer structural analysis. The licensee stated that in the strainer component and supporting structure final stress evaluation, the limits of the ASME B&PV Code, Subsection NF, "Supports," are satisfied for the original loading conditions. The licensee also stated that the requirements of the AISC Manual of Steel Construction were also considered for the perforated plates used in the strainer.

The licensee stated that the strainer assembly is capable of bearing a differential pressure of 12 ft water column at 170 °F, if ASME limits are used for the plate and shell type parts of the frame support. The stresses in the sub-floor structure consisting mainly of a beam type design are still below the AISC limits for the target loading (12 ft water column at 170 °F). Therefore, the licensee concluded that the maximum allowable pressure difference is 12 ft water column at 170 °F for all three major strainer components (cartridge, module, and sub-floor).

NRC Staff Conclusion

For this review area, the licensee has provided information such that the NRC staff has reasonable assurance that the sump strainer assemblies will remain structurally adequate under normal and abnormal loading conditions such that the assemblies will be able to perform their intended design functions.

The NRC staff concludes that this area has been adequately addressed by the licensee. The NRC staff considers this item closed for GL 2004-02 for Palo Verde.

14.0 UPSTREAM EFFECTS

The objective of the upstream effects assessment is to evaluate the flow paths upstream of the containment sump for holdup of inventory, which could reduce flow to the sump.

NRC Staff Review

The NRC staff review is based on documentation provided by the licensee through December 18, 2013.

The licensee stated that the path of water flow through the containment upstream of the containment emergency sumps during a LOCA might be affected by debris collecting at possible restrictions. The licensee reviewed equipment location drawings to determine likely flow paths and possible choke points. Consistent with the guidance in NEI 02-01, a walkdown of the flow paths for all floor elevations was conducted in Palo Verde, Unit 2. Based on design similarities between Units 1, 2, and 3, the Unit 2 walkdown results are applicable to all Units. The walkdown verified that clear flow paths exist to the sumps such that injected water would not be held up and could freely flow back to the sumps. No choke points were identified.

The licensee also evaluated flow paths from postulated breaks and CS washdown to ensure water from these sources would not be held up. No choke points or other holdups that could prevent water from reaching the sump were identified.

The licensee evaluated the potential for water holdup in the refueling cavity. This was considered an important flowpath because it is exposed to a significant portion of CS flow and has a large volume. The cavity has two 10-inch diameter drain pipes in the floor. One drain pipe is west of the reactor and the other is east of the reactor, and both pipes drain to the elevation 80 ft. The licensee evaluated the potential for large pieces of debris to migrate to the drains and restrict the flow to the sump. Blockage of the east 10-inch drain opening would not result in an appreciable water hold up because the cavity in that area is relatively shallow. The lower west part of the refueling cavity is deeper with greater floor area to gather CS flow, which could hypothetically hold thousands of cubic feet of water if its drain were blocked.

The reactor vessel head insulation was originally a hybrid design consisting of both metal and non-metallic insulation. The insulation is now fully RMI. The licensee evaluated the reactor head insulation and other insulation sources and determined it is unlikely that the refueling cavity drains would become blocked with debris. However, the licensee assumed that the debris generated due to the LOCA will block the reactor cavity drain line. The volume of the reactor cavity was assumed to hold up water in the licensee’s determination of minimum containment flood level. The licensee had originally assumed that the drain lines would not become blocked, but changed its assumption based on NRC staff concerns with the original assumption. The final assumption is conservative because it is unlikely that the drains would become blocked.

The NRC staff reviewed the licensee’s RAI responses and supplemental information through December 18, 2013. The NRC staff noted that containment drawing evaluation and walkdowns were performed in accordance with the guidance of NEI 02-01 to identify potential holdup and choke points. These walkdowns did not identify any choke points.

The debris generated due to a LOCA is assumed to block the reactor cavity drain line in the determination of minimum containment flood level. The possibility of the two 10-inch refueling cavity drains becoming blocked is highly unlikely due to the characteristics of the debris that could reach the drains. Holdup volumes are appropriately considered in the calculation of LOCA minimum water level.

NRC Staff Conclusion

For this review area, the licensee has provided information such that the NRC staff has reasonable assurance that the subject review area has been addressed conservatively or prototypically. The NRC staff concludes that the upstream effects area has been adequately addressed by the licensee. The NRC staff considers this item closed for GL 2004-02 for Palo Verde.

15.0 DOWNSTREAM EFFECTS - COMPONENTS AND SYSTEMS

The objective of the downstream effects, components and systems section is to evaluate the effects of debris carried downstream of the containment sump screen on the function of the ECCS and CSS in terms of potential wear of components and blockage of flow paths.

NRC Staff Review

The NRC staff review is based on documentation provided by the licensee through December 18, 2013, as supplemented by the December 1, 2016, submittal.

The licensee's December 18, 2013, submittal, contained the information requested in the content guide. The licensee stated that it evaluated the downstream effects of debris ingested into the ECCS during containment sump recirculation operation using the methods described in Revision 1 of WCAP-16406-P-A, including the limitations and conditions contained in the associated NRC SE. The evaluation addressed the effect of debris ingestion on equipment in the ECCS and CSS, including valves, pumps, heat exchangers, orifices, spray nozzles, and instrumentation. The equipment evaluations included erosive wear, abrasion, and potential blockage of flow paths. The evaluations show that the ECCS equipment at Palo Verde will remain capable of passing sufficient flow to the reactor to adequately cool the core during the recirculation phase of a postulated LOCA.

Because the licensee demonstrated that the ECCS equipment downstream of the ECCS sump strainers can perform its safety-related functions to mitigate the consequences of a HELB or LOCA using analytical methods prescribed in WCAP-16406-P-A, Revision 1, and the associated NRC SE (including limitations and conditions), the NRC staff concluded that the downstream effects of debris-laden recirculated sump fluid on ex-vessel downstream components and systems had been adequately addressed at Palo Verde.

On December 1, 2016, the licensee provided a supplemental response to address the newly discovered Microtherm, Temp-Mat, and Nukon insulation, which were discovered in April 2015, spring 2016, and fall 2015, respectively. The licensee provided a list of equipment potentially subject to wear from post-LOCA particulate debris, including Microtherm from RPV nozzle breaks, as well as references containing the evaluations performed for the equipment.

The licensee stated that Microtherm is equivalent to small, 10 micron IOZ particles, which does not add to abrasive wear of equipment. The licensee also stated that the maximum revised coating mass concentration, including Microtherm contribution from reactor vessel nozzle breaks is 403 parts per million (ppm), which compares favorably with the previously analyzed value of 982 ppm for the wear evaluations. Therefore, the licensee concluded that existing analyses related to the ECCS pump seal cyclone separators and ECCS equipment and valves remain bounding.

NRC Staff Conclusion

The NRC staff reviewed the description of the analyses as described in the licensee's GL 2004-02 response to Item (m) in letter dated December 18, 2013, as well as the supplemental information provided in the December 1, 2016, submittal. Because the licensee demonstrated that the ECCS equipment downstream of the ECCS sump strainers can perform its safety-related functions to mitigate the consequences of a HELB or LOCA using approved analytical methods prescribed in WCAP-16406-P-A, Revision 1, and the associated NRC SE (including limitations and conditions), the NRC staff concludes that the downstream effects of debris-laden recirculated sump fluid on ex-vessel downstream components and systems had been adequately addressed at Palo Verde. The NRC staff considers this item closed for GL 2004-02.

16.0 DOWNSTREAM EFFECTS - FUEL AND VESSEL

The objective of the downstream effects, fuel, and vessel section is to evaluate the effects that debris carried downstream of the containment sump screen and into the reactor vessel has on LTCC.

The NRC staff review is based on the licensee's December 18, 2013, submittal, as supplemented by an addendum dated December 1, 2016, and the final February 22, 2022, submittal. The guidance documents used for the review include the content guide and WCAP-16793-NP-A.

The licensee stated since the existing sump screen with 0.09 inch mesh openings is smaller than the maximum acceptable hole size from the reactor vessel internals evaluation (0.37 inch), there is no concern for plugging of reactor vessel internals flow paths.

The licensee performed a plant-specific evaluation for Palo Verde using WCAP-16793-NP-A, and the associated NRC SE. The evaluation results for Palo Verde are:

1. The maximum calculated cladding temperature is 369 °F. This is less than the WCAP-recommended maximum cladding temperature of 800 °F.

2. The total deposition thickness is 0.0043 inch (4.3 mils). This is less than the recommended total debris deposition thickness of 0.050 inch.

3. Based on Palo Verde-specific strainer bypass testing, the fiber calculated to bypass the strainers and reach the fuel assembly is 12.8 grams per fuel assembly. This quantity is less than the WCAP-16793-NP-A acceptance criteria of 15 grams per fuel assembly. The amount was updated to 13.8 grams per fuel assembly as discussed below. This value remains below the acceptance criteria.

Also, in the submittal dated December 18, 2013, the licensee stated that its analysis is in compliance with the 14 Limitations and Conditions of the NRC SE of WCAP-16793-NP-A. Based on the above information, the NRC staff concludes that Palo Verde meets the requirements specified in WCAP-16793-NP-A, and the specifications, limitations, and conditions listed in the associated NRC SE. Therefore, Palo Verde is in compliance with the requirements of GL 2004-02 for downstream effects in the fuel and vessel.

On December 1, 2016, the licensee provided a supplemental response to address the newly discovered Microtherm, Temp-Mat, and Nukon insulation, which were discovered in April 2015, spring 2016, and fall 2015, respectively. The licensee provided Table 4-20 comparing the bypass fiber mass per fuel assembly reported in its December 18, 2013, submittal to the new design configuration after recommended insulation removal. The results in the table show that the fiber load increased from 12.8 grams per fuel assembly, as reported in the December 18, 2013, submittal, to 13.8 grams per fuel assembly, which is less than the 15 grams per fuel assembly limit in WCAP-16793.

In its February 22, 2022, submittal the licensee provided updated information as follows:

1. The maximum calculated cladding temperature is 369 °F. This is less than the WCAP-recommended maximum cladding temperature of 800 °F.

2. The total deposition thickness is 0.0049 inch (4.9 mils or 125.7 microns). This is less than the recommended total debris deposition thickness of 0.050 inch.

3. Based on Palo Verde-specific strainer bypass testing, the fiber calculated to bypass the strainers and reach the fuel assembly is 13.8 grams per fuel assembly. This quantity is less than the WCAP-16793-NP-A acceptance criteria of 15 grams per fuel assembly.

The licensee stated that Next Generation Fuel (NGF) was approved for installation at Palo Verde in 2018. This fuel change did not affect applicability of the evaluations since they apply to all fuel designs used in Palo Verde cores, including NGF. In 2020, Framatome HTP™ fuel was approved for installation at Palo Verde. Based on the NRC staff SE for that approval, the loading of that fuel would not be expected to exacerbate the potential for post-LOCA debris blockage in the reactor vessel. This conclusion was based upon the limited quantity of fibrous debris expected at Palo Verde following a LOCA event, as well as conservatisms inherent in the WCAP-16793-NP-A methodology. The licensee stated that the in-vessel effects evaluation methods and results upon which this NRC conclusion was based are unchanged.

<u>NRC Staff Conclusions</u>

The NRC staff reviewed the description of the analyses, strainer bypass testing, and compliance with the limitations and conditions of WCAP-16793-NP-A, as described in the licensee's GL 2004-02 response to Item (n), as well as the supplemental information provided in the December 1, 2016, and February 22, 2022, submittals and find that the licensee response addressing IVDE for Palo Verde, satisfies the requirements stated in WCAP-16793-NP-A, Revision 2, and the associated NRC SE. Palo Verde has also provided information that shows that its ECCS strainers will function considering the debris that may be generated during a design basis LOCA or HELB and transported to the ECCS sump strainer.

17.0 CHEMICAL EFFECTS

The objective of the chemical effects section is to evaluate the effect that chemical precipitates have on head loss and core cooling.

NRC Staff Review

The initial NRC staff review is based on documentation provided by the licensee through February 29, 2008. Based on this information, the NRC staff asked an RAI requesting the licensee to provide the chemical effects information requested by the Revised Content Guide dated November 2007 for chemical effects as provided in Enclosure 3 of a letter from the NRC to NEI dated March 28, 2008 (ADAMS Accession No. ML080380214).

The final staff review is based on the licensee's letter dated March 13, 2009. In this letter, the licensee provided supplemental information, including greater detail about its chemical effects related testing. The final NRC staff review is also based on the licensee's December 1, 2016 supplement.

On December 1, 2016, the licensee provided an addendum to its supplemental response to address the newly discovered Microtherm, Temp-Mat, and Nukon insulation, which were discovered in April 2015, spring 2016, and fall 2015, respectively.

The licensee stated that it used the WCAP-16530-NP spreadsheet to estimate the chemical particulate quantities associated with the analysis cases that represent the current condition, after planned Temp-Mat removal is accomplished. The licensee presented the fiber and Microtherm inputs and resulting total quantity of chemical particulate quantities from WCAP-16530-NP spreadsheet calculations. The licensee also presented the "normalized" total precipitate quantity and clarified that "normalized" total precipitate quantity is defined as current condition precipitate quantity divided by the net surface area per strainer (i.e., 2,742 ft^2 per strainer train).

The licensee stated that the maximum normalized quantity of chemical precipitate for the current condition, after planned Temp-Mat removal is accomplished, is 0.096 $lb./ft^2$, which is less than the normalized quantity of chemical precipitate used in the head loss test of record, 0.0997 $lb./ft^2$. Therefore, the amount of chemicals included in the test program bound those calculated as potentially occurring considering the newly discovered insulation.

However, the NRC staff has to consider the combined effects of chemical precipitates and the added insulation debris. The comparison test, originally performed for Salem, discussed in the Head Loss section contained limiting quantities of almost all debris types, including fiber and microporous insulation and also contained higher chemical precipitate quantities per screen area. This test is now incorporated into the licensee's evaluation as the limiting test for lower temperatures. The Palo Verde test is limiting at higher temperatures because of the assumptions made regarding the timing of chemical precipitation. The Salem analysis assumed that chemical effects would not occur until the pool temperature cooled to 160 °F. The Palo Verde analysis assumed that precipitation would occur immediately because they had margin available to support this assumption. The Palo Verde evaluation now uses the limiting head loss from either the Palo Verde or the Salem head loss analysis at each temperature. The NRC staff concluded that it is valid for Palo Verde to assume precipitation will not occur until temperature in the pool is reduced to 160 °F.

If Palo Verde had initially assumed this in its head loss analysis, its head loss values at higher temperatures would have been significantly lower. Because the delayed chemical precipitation analysis is valid for the Palo Verde plant condition, the use of the Salem analysis combined with the Palo Verde analysis is acceptable.

The licensee stated for chemical effects that its updated analysis assumes that the reactor cavity will flood and flow to the D-ring via Vaneaxial fan ducts and 051-XCDA-4. The updated analysis also considers the removal of the newly discovered Nukon insulation which would not be damaged during a LOCA but could be submerged and contribute to the chemical source term in the pool. The removal of this insulation eliminates the need to consider it further.

NRC Staff Conclusion

For this review area, the licensee has provided information such that the NRC staff has reasonable assurance that the subject review area has been adequately addressed. The licensee has provided information such that the reviewer has high confidence in the licensee's test and evaluation methods in this subject area.

The licensee performed a chemical effects evaluation using the WCAP-16530-NP-A base method without refinements and with conservative assumptions (e.g., assuming CS remains on for 30 days) to maximize the amount of chemical precipitate generated. The licensee performed sump strainer testing and simulated chemical effects by adding pre-mixed precipitate formed according to the WCAP-16530-NP-A protocol. The NRC staff visited the test vendor facilities, observed the plant specific chemical effects testing for Palo Verde and determined that the test vendor's implementation of the WCAP-16530-NP-A protocol was acceptable. The NRC staff's trip report to the strainer vendor's test facility is available in ADAMS (Accession No. ML081640193).

The overall chemical effects evaluation for Palo Verde is acceptable since the licensee used a methodology (WCAP-16530-NP-A) that has been previously reviewed and accepted by the NRC staff. The NRC staff's SE of the WCAP-16530-NP methodology is available in ADAMS at Package Accession No. ML073521294. In addition, the NRC staff also observed Palo Verde strainer tests that included chemical precipitate addition and had no issues with how the test vendor implemented the WCAP-16530 methodology. Therefore, the NRC staff considers this item closed for Palo Verde's GL 2004-02 response.

18.0 LICENSING BASIS

The objective of the licensing basis section is to provide information regarding any changes to the plant licensing basis due to the changes associated with GL 2004-02.

NRC Staff Review

The licensee committed to change the UFSAR in accordance with 10 CFR 50.71(e) to reflect the changes to the plant in support of the resolution to GL 2004-02.

In addition, the licensee stated that changes would be made to the UFSAR describing the new licensing basis to reflect the revised debris loading as it affects ECCS sump strainer performance and in-vessel effects, including the following:

- Break Selection
- Debris Generation
- Latent Debris
- Debris Transport
- Head Loss
- Additional Design Considerations

The NRC staff has reviewed all the information provided by the licensee for closure of GL 2004-02, and finds that Palo Verde meets the in-vessel criteria contained in the NRC staff SE to WCAP-16793-NP-A. The licensee has also provided information that shows that Palo Verde's ECCS strainers will function considering the debris that may be generated during a design basis LOCA or HELB and transported to the ECCS sump strainer.

NRC Staff Conclusion

For this review area the licensee provided information, such that the NRC staff has reasonable assurance that the subject review area has overall been addressed conservatively or prototypically. Therefore, the NRC considers this item closed for GL 2004-02.

19.0 CONCLUSION

The NRC staff performed a thorough review of the licensee's responses and RAI supplements to GL 2004-02. The NRC staff conclusions are documented above. Based on the above evaluations the NRC staff finds the licensee has provided adequate information as requested by GL 2004-02.

The stated purpose of GL 2004-02 was focused on demonstrating compliance with 10 CFR 50.46. Specifically, the GL requested addressees to perform an evaluation of the ECCS and CSS recirculation and, if necessary, take additional action to ensure system function in light of the potential for debris to adversely affect LTCC. The NRC staff finds that the information provided by the licensee demonstrates that debris will not inhibit the ECCS or CSS performance following a postulated LOCA. Therefore, the ability of the systems to perform their safety functions, to assure adequate LTCC following a DBA, as required by 10 CFR 50.46, has been demonstrated.

Therefore, the NRC staff finds that the licensee's responses to GL 2004-02 are adequate and considers GL 2004-02 closed for Palo Verde Units 1, 2, and 3.

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Date: April 27, 2022

SUBJECT: PALO VERDE NUCLEAR GENERATING STATION, UNITS 1, 2, AND 3 - CLOSEOUT OF GENERIC LETTER 2004-02, “POTENTIAL IMPACT OF DEBRIS BLOCKAGE ON EMERGENCY RECIRCULATION DURING DESIGN BASIS ACCIDENTS AT PRESSURIZED-WATER REACTORS” (EPID L-2017-LRC-0000) DATED: APRIL 27, 2022

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