UNITED STATES
NUCLEAR REGULATORY COMMISSION
REGION III
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June 21, 2012

Mr. Barry Allen
Site Vice President
FirstEnergy Nuclear Operating Company
Davis-Besse Nuclear Power Station
5501 North State Route 2, Mail Stop A-DB-3080
Oak Harbor, OH 43449-9760

SUBJECT: DAVIS-BESSE NUCLEAR POWER STATION - INSPECTION TO EVALUATE THE ROOT CAUSE EVALUATION AND CORRECTIVE ACTIONS FOR CRACKING IN THE REINFORCED CONCRETE SHIELD BUILDING OF THE CONTAINMENT SYSTEM 05000346/2012009(DRS)

Dear Mr. Allen:

On May 9, 2012, the U.S. Nuclear Regulatory Commission (NRC) completed an inspection to evaluate your root cause evaluation and corrective actions associated with discovery of laminar subsurface cracks, in the reinforced concrete shield building at the Davis Besse Nuclear Power Station. These cracks were discovered on October 10, 2011, by your staff while performing hydrodemolition operations in support of reactor vessel head replacement. The NRC had previously initiated an inspection in accordance with the special and infrequently performed inspection procedure (IP) 71007 “Reactor Vessel Head Replacement” and confirmed adequate restoration of the containment system to assure functional integrity (NRC inspection reports (IR) 05000346/2011-005 and 05000346/2012-007). In addition, the later report discussed your assessment and the associated NRC review, that the shield building remained capable of performing its safety functions despite the cracking.

During the current inspection, the NRC inspection team reviewed your Root Cause Analysis Report - Concrete Crack Within Shield Building Temporary Access Opening, observed supporting vendor tests, and interviewed your personnel assigned to the root cause investigation to determine if you had adequately determined the causes for the laminar cracking identified in the shield building exterior wall. The NRC team confirmed that your Rout Cause Analysis Team as augmented with vendor subject matter experts was appropriately trained, followed site procedures for root cause investigations, and had considered relevant site and external operating experience. The NRC team concluded that your staff established a sufficient basis for the causes of the shield building laminar cracking related to: the environmental factors associated with the 1978 blizzard, the lack of an exterior moisture barrier, and the structural design elements of the shield building. Specifically, the weather records, core boring sample results, impulse response testing, and shield building analytical modeling provided a sufficient basis to support the causes of the laminar cracking. The NRC team identified minor weaknesses in the Root Cause Analysis Report associated with the level of detail in the documentation provided. These weaknesses did not constitute performance deficiencies or findings because they did not adversely affect the outcome of the root cause process.

The NRC team also reviewed your corrective actions to address the causes of the shield building laminar cracking. The team identified two examples where the scope of your corrective actions to address the causes of the shield building cracking was too narrow.

- You had not proposed examinations to confirm a lack of subsurface cracking in other safety-related building structures with installed moisture barriers to further substantiate the Direct Cause.
- Your corrective action for the Root Cause included updating a site procedure for inspections of only the shield building exterior sealant system instead of a broader action to inspect all safety-related buildings with moisture barriers.

Your staff has entered the team's observations into the corrective action system, and we understand that you are considering actions to expand the scope of these corrective actions.

Additionally, the NRC has ongoing reviews as part of your Davis-Besse License Renewal Application that will evaluate your proposed program for monitoring of the shield building cracking. Overall, the team concluded that your corrective and preventative actions for the causes of the shield building laminar cracking, if adequately implemented, would prevent recurrence, and provide reasonable assurance for maintaining the shield building safety functions. The attached inspection report documents the inspection results for our review of your root cause evaluation activities and proposed corrective actions associated with your root cause report submitted to the NRC on February 28, 2012, (Reference ADAMS Accession No. ML120600056), and which were discussed with you and your staff at the exit meeting held on May 9, 2012.

Additionally, we have received and will review changes contained in Revision 1 of your root cause report (Reference ADAMS Accession ML12142A053) as part of our follow-up inspections planned for the shield building issue. As discussed with your staff, a public meeting will be scheduled in the near future to allow the opportunity for FirstEnergy Nuclear Operating Company to describe its root cause activities and planned actions going forward and NRC staff to discuss the related NRC inspection described in the enclosed report.

In accordance with 10 CFR 2.390 of the NRC's "Rules of Practice," a copy of this letter, its enclosure and your response (if any) will be available electronically for public inspection in the NRC Public Document Room or from the Publicly Available Records System (PARS) component of NRC's document system (ADAMS). ADAMS is accessible from the NRC Web site at http://www.nrc.gov/reading-rm/adams.html (the Public Electronic Reading Room).

Sincerely,

/RA/
Steven A. Reynolds, Director
Division of Reactor Safety

Docket Nos. 50-346
License Nos. NPF-3

Enclosure: Inspection Report 05000346/2012009(DRS)

Attachment 1: Supplemental Information
Attachment 2: Photos and Diagrams

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U.S. NUCLEAR REGULATORY COMMISSION

REGION III

Docket No:	50-346
License No:	NPF-3
Report No:	05000346/2012009
Licensee:	FirstEnergy Nuclear Operating Company (FENOC)
Facility:	Davis-Besse Nuclear Power Station
Location:	Oak Harbor, OH
Dates:	December 1, 2011 through May 9, 2012
Inspectors:	M. Holmberg, Team Lead J. Neurauter, Inspector E. Sanchez Santiago, Inspector A. Shaikh, Inspector
Approved by:	D. E. Hills, Chief Engineering Branch 1 Division of Reactor Safety

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SUMMARY OF FINDINGS

IR 05000346/2012-009(DRS); 12/01/2011 - 5/09/2012, Davis-Besse Nuclear Power Station; Inspection to Evaluate the Root Cause and Corrective Actions for Cracking in the Reinforced Concrete Shield Building of the Containment System.

This report covers a 5-month period of inspection by a team of NRC regional inspectors. No findings were identified. The significance of most findings is indicated by their color (Green, White, Yellow, Red) using Inspection Manual Chapter (IMC) 0609, "Significance Determination Process" (SDP). Findings for which the SDP does not apply may be "Green" or be assigned a severity level after NRC management review. The NRC's program for overseeing the safe operation of commercial nuclear power reactors is described in NUREG-1649, "Reactor Oversight Process," Revision 4, dated December 2006.

A. Inspector-Identified and Self-Revealed Findings

No findings were identified.

B. Licensee-Identified Violations

No violations were identified.

REPORT DETAILS

SHIELD BUILDING DESCRIPTION

The containment system for the Davis-Besse site consists of three basic structures: a steel containment vessel (CV), a reinforced concrete shield building (SB), and the internal structures. The CV is a cylindrical steel pressure vessel with hemispherical dome and ellipsoidal bottom which houses the reactor vessel, reactor coolant piping, and other safety-systems. The CV is completely enclosed by a reinforced concrete SB (Attachment 2, Picture 1) having a cylindrical shape with a shallow dome roof. An annular space is provided between the steel CV and the interior face of the concrete SB of approximately 4.5 feet (ft) to permit construction operations and periodic visual inspection of the steel containment vessel. The SB has an inside radius of 69.5 ft and a height of 279.5 ft measured from the top of the foundation ring to the top of the dome. The thicknesses of the SB wall and the dome are approximately 2.5 ft and 2 ft, respectively, and the exterior SB wall has eight vertical cutouts (called flutes) spaced 45 degrees apart. These flutes consist of shoulders that extend another 1.5 ft outward and gradually taper back to the outer cylindrical wall of the SB while reaching a point of tangency 17 ft 11 inches from the centerline of the flute (Attachment 2, Picture 2). The CV and SB are supported on a concrete foundation founded on a firm rock structure. With the exception of the concrete under the CV, there are no structural ties between the CV and the SB above the foundation slab. The CV provides the primary means to contain the post accident environment and is designed to withstand and hold against accident induced pressure. The identified cracking does not involve the CV. The design of the SB provides for: shielding from radiation sources within the SB, controlled release of annulus atmosphere under an accident condition, and environmental protection of the CV.

BACKGROUND AND OVERVIEW

The Davis-Besse CV and SB lacked an access opening of sufficient size to permit removal of the old reactor vessel head and reinstallation of the replacement vessel head. Therefore, during the 17-mid-cycle outage, the licensee cut a temporary access opening in the SB and CV of sufficient size to support head replacement. The licensee reused and re-installed by welding the original plate section cut from the CV, to restore the temporary construction opening in the CV. The licensee installed new reinforcing steel (i.e., rebar) to replace the original steel reinforcement and poured new concrete from an on-site batch plant, to restore the temporary construction opening in the SB. The inspectors reviewed the licensee activities associated with the restoration of the CV and SB access openings as documented in NRC inspection reports 05000346/2011005 and 05000346/2012007.

During construction of the SB access opening in the 17-mid-cycle outage, the licensee discovered subsurface cracking located near the outer rebar mat, which extended into areas of the SB that not been modified since original construction. The licensee attempted to remove the cracks discovered during the hydrodemolition process (Attachment 2, Picture 3) using a manual chipping process. Using this method, the crack indications along the left and bottom edges essentially disappeared, but the crack at the top of the opening did not disappear. The licensee investigated and confirmed the extent of subsurface laminar cracking through the use of impulse response (IR) testing and core boring samples (CBS) taken from the SB. Specifically, laminar subsurface concrete cracks were identified along the outer rebar mat in the SB flute shoulders, at the top of SB near the junction with the roof, and at the SB penetration openings. The licensee was able to demonstrate that the SB remained structurally adequate for the controlling load cases and remained capable of performing its safety functions. However,

the SB areas with the laminar subsurface cracking were non-conforming with respect to the SB design and licensing bases. The licensee's analysis and associated NRC review are discussed in NRC inspection report 05000346/2012007.

The NRC issued a Confirmatory Action Letter (CAL) No. 3-11-001 (ADAMS Accession No. ML11336A355) to document the licensee actions required to demonstrate long-term confidence in the SB integrity. These actions included providing the NRC with the results of the root cause evaluation and corrective actions for the SB cracking.

4. OTHER ACTIVITIES

Cornerstones: Initiating Events, Mitigating Systems, Barrier Integrity, and Emergency Preparedness

4OA5 OTHER ACTIVITIES

.1 Reactor Vessel Head Replacement (Inspection Procedure 71007) – Containment Restoration- Shield Building Laminar Cracking Root Cause Evaluation and Corrective Action (CA) Review

a. Inspection Scope

The licensee chartered a root cause analysis team (RCT) supported by vendor subject matter experts knowledgeable in concrete construction, design, examination, and modeling to review evidence associated with the discovery of subsurface concrete cracking in the flute region of a temporary access opening in the SB wall. The laminar cracking was primarily associated with the shoulder regions, although some cracking was identified outside the shoulder regions near the main steam lines and near the top of the SB cylinder. The cracks were very tight (meaning the gap between the crack surfaces was extremely small). No cracking was identified inboard of the outer rebar mat (deeper toward the inner wall surface) around either the equipment access opening or in the core borings. The cracking was interior to the wall surface and was not visually discernable until the licensee cut into the wall to create the access opening. The licensee's RCT was tasked with determining "how," "when," and "why" the concrete cracking occurred in the SB wall. The results of the licensee's root cause evaluation and proposed CAs were submitted to the NRC on February 28, 2012, as documented in a Root Cause Analysis Report (RCR) - Concrete Crack within Shield Building Temporary Access Opening (Reference ADAMS Accession No. ML120600056).

From December 1, 2011 through May 9, 2012, the NRC team reviewed the licensee's investigation of the causes for the SB laminar cracking as discussed below to determine if: (1) the scope of the operating experience (OE) review considered relevant Davis-Besse SB degradation history and related industry experiences to develop an adequate scope of potential causes; (2) the causes for the SB cracking were adequately ascertained using a scrutable process; and (3) the CAs proposed for the identified causes were sufficient to prevent recurrence and ensure the continued capability of the SB to perform the design basis functions.

The activities reviewed by the NRC team included:

- Observation of the equipment and review of the process followed by one of the three laboratories performing the petrographic examinations on the SB concrete core boring samples (CBS),

- Observation of vendor tests conducted at offsite laboratories on concrete CBS removed from the SB. Specifically, the team observed portions of the concrete compression test, splitting tensile strength test, accelerated creep test, and a freeze-thaw test,

- Observation of the SB exterior concrete surfaces accessible from the auxiliary building roof level and at three CBS locations (S7-667.0-25, S7-666.0-7 and S6-665-47) utilizing a boroscope,

- Review of the RCR, the supporting vendor report (Performance Improvement International - Root Cause Assessment Davis-Besse Shield Building Laminar Cracking), technical specifications for the SB, condition reports (CRs), nonconformance reports (NCRs) and the SB related drawings for construction, design and IR testing results,

- Review of the inputs and assumptions for the licensee's vendor analysis and modeling applied in support of (or to refute) the potential SB failure modes, and

- Interviews of licensee RCT members and supporting vendor staff.

b. Observations and Conclusions

b.1 Licensee OE Review and Potential Causes

The licensee discovered subsurface laminar cracking in the SB located near the outer rebar mat which extended into areas that had not been modified since original construction. To determine the extent of cracking, the licensee applied an acoustic sounding technique (hereafter referred to as IR testing) on the SB exterior wall to identify areas with laminar cracking (Attachment 2, Pictures 4 and 5). Confirmation of the IR test results was achieved by visual inspection of 70 CBS (Attachment 2, Pictures 6 and 7). The licensee's initial condition assessment determined that the SB concrete wall contained tight width laminar cracking near the outer face of structural reinforcing steel and the majority of the laminar cracking occurred in the concrete at the outer face of structural reinforcing steel located behind the flute shoulder regions. Some laminar cracking occurred beyond the flute shoulder region as evident across the top 20 feet of the SB and in localized areas adjacent to one side of each mainsteam line penetration blockout. The southwestern exposure of the SB wall was observed with the most extensive laminar concrete cracking. The licensee contracted vendors to examine 36 SB concrete CBS (Attachment 2, Picture 8) to identify possible failure modes for the laminar cracking, or quantify material properties of the concrete in support of computer modeling and analysis.

The RCT identified that a majority of the nuclear power stations which have constructed temporary access openings in containment systems are either post-tensioned or reinforced concrete cylinders with a steel liner (both designs differ from the Davis-Besse

SB, which is a reinforced concrete structure without post-tension system and/or a liner). The RCT identified that the only previous OE of concrete delamination at a nuclear power plant occurred at Crystal River Unit 3 and was discovered while creating a temporary access opening in the containment structure. The root cause of the Crystal River Unit 3 containment concrete delamination was the design of the structure in combination with the type of concrete used, and the acts of de-tensioning and opening the containment structure.

The RCT also identified a study of the deterioration of concrete water storage tanks in the province of Ontario Canada where damage was identified that ranged from heavy surface spalling and cracking to delamination and eventual failure of some structures. This study concluded the prime factors for determining the rate of concrete structure deterioration were the number of freeze /thaw cycles, temperature amplitudes and frequencies, concrete permeability, hydrostatic pressure, location, the effect of reinforcing steel, and internal ice formation.

The RCT developed a fault tree of 45 possible failure modes that could potentially contribute to the laminar cracking, either individually or in concert based upon characteristics of the SB laminar cracking and other OEs with concrete issues. The 45 failure modes were grouped into three major categories consisting of Design, Construction and Fabrication, and Operational (Attachment 2, Picture 9) and each of these failure modes was evaluated during the root cause investigation. In general, each failure mode was either refuted or supported by laboratory tests and examinations or analysis. Some failure modes were refuted by deductive reasoning based on existing evidence to either support or refute their mode of failure. Potential failure modes were not eliminated without evidence to refute the postulated failure mode.

The licensee's vendor analyzed the SB for the loading conditions that could not be refuted in the Failure Modes Analysis, such as seismic, snow/ice, or dead weight of the dome. Additionally, the licensee's vendor applied concrete stress and fracture analysis modeling techniques originally developed as part of the Crystal River Unit 3 containment concrete delamination/cracking root cause investigation. The vendor modeling and analysis was updated to reflect the design characteristics of the Davis-Besse SB. The material properties and failure criteria used in the analysis and modeling were based upon the results of the SB concrete laboratory tests and examinations. The five vendor analyses supporting the RCT investigation were the:

- Freezing Failure and Rebar Spacing Sensitivity Study;
- Structural and Thermal Analysis Investigation;
- Stress State Environmental Conditions During the 1977 and 1978 Blizzards;
- Stress Analysis Due to 105 MPH Wind Load; and
- Laminar Cracking Due to Environmental Conditions during the 1978 Blizzard.

The RCT also considered information available in industry documents related to concrete degradation for the development of potential failure modes and CAs. Specifically, the documents reviewed by the RCT included: Nuclear Regulatory Commission, "Primer on Durability of Nuclear Power Plant Reinforced Concrete

Structures – A Review of Pertinent Factors," NUREG/CR-6927, American Concrete Institute (ACI) 349.3R-02, "Evaluation of Existing Nuclear Safety-Related Concrete Structures," Electric Power Research Institute, "Program on Technology Innovation: Concrete Civil Infrastructure in United States Commercial Nuclear Power Plants," 1020932, International Atomic Energy Agency, "Assessment and Management of Aging of Major Nuclear Power Plant Components Important to Safety – Concrete Containment Buildings," IAEA-TECDOC-1025, ACI 224.1R-07, "Causes, Evaluation, and Repair of Cracks in Concrete Structures," and ACI 515.1R-79, "A Guide for the Use of Waterproofing, Damp Proofing, Protective, and Decorative Barrier Systems for Concrete."

b.2 NRC Team Conclusions on OE and Potential Causes

The NRC team evaluated if the RCT had made appropriate use of OE to develop a sufficiently comprehensive list of potential causes for the SB laminar cracking. To perform this evaluation, the NRC team completed a walkdown of the SB exterior concrete surfaces accessible from the auxiliary building roof level and at three core bore locations (S7-667.0-25, S7-666.0-7 and S6-665-47) utilizing a boroscope, and observed vendor tests/exams conducted at offsite laboratories on CBS removed from the SB. The NRC team also reviewed the RCR, supporting vendor reports, the SB technical specifications, CA records, drawings of IR mapping results, SB construction/design drawings and OEs documented in two NRC technical reports (NUREGs) associated with reinforced concrete structures used in nuclear power plants. Based upon this review, the NRC team concluded that the RCT had considered and appropriately applied relevant site and external OE to identify a comprehensive scope of potential failure modes that could contribute to or cause the SB laminar cracking.

The NRC team also concluded that the RCT had established a sufficient basis to refute/exclude 39 of the 45 failure modes as potential causes for the SB cracking with one exception. The NRC team identified that the RCR had not recorded a sufficient basis to eliminate slipform induced laminar cracking in the Failure Mode Analysis process. Subsequently, the RCT provided sufficient explanation to confirm that slipform induced cracking was not a possible cause for the SB laminar cracking and the NRC team concluded that this issue was an example of a minor documentation weakness in the RCR. The remaining six failure modes (e.g., not refuted) were determined to be associated with the direct, root or contributing causes of the SB laminar cracking.

Additional details of the NRC team's review of this area are provided in Sections b.2.1 and b.2.2 below.

b.2.1 NRC Team Evaluation of RCT Use of OE

The NRC team examined three core bore locations (S7-667.0-25, S7-666.0-7, and S6-665-47) with the aid of a boroscope and performed a direct visual examination of exterior SB concrete surfaces accessible from the auxiliary building roof level to evaluate the condition of the SB and confirm the location of laminar cracking recorded in the RCR. Based upon these examinations, the NRC team did not identify any discrepancies with the location or characterization of cracking recorded in the licensee's RCR. Further, the exterior concrete surfaces and interior concrete conditions within SB bore holes were consistent with that recorded in the licensee's CRs with one minor exception.

The NRC team identified a brown deposit located near the bottom of a core bore at location S7-667.0-25, which had not been recorded on a licensee CR. The licensee staff believed this deposit was rust related stain and documented this condition in CR-2012-03889. The NRC team reviewed photographs from other SB core bore locations and noted a similar condition in the first core bore location (S15-645.5-3). The licensee staff believed this stain/deposit could be the results of minor rebar corrosion caused by water introduced during the core bore drilling operation. The licensee's corrective action associated with the identified corrosion is subject to future NRC inspection.

The licensee identified previous OE related to degradation of concrete water tanks in Ontario damaged by delamination and spalling due to a similar set of conditions that affected the SB. The only previous nuclear related OE with subsurface delamination identified by the licensee RCT was the Crystal River 3 containment delamination event. The causes for the Crystal River 3 cracking event were related to the design of the structure in combination with the type of concrete used, and the act of de-tensioning and opening the containment structure. Therefore, the NRC team agreed with the RCT that the causes for the Crystal River 3 event differed from the causes of the SB cracking. The NRC team reviewed relevant site and external OE data pertaining to concrete cracking issues experienced by concrete structures used in nuclear power plants to assess the scope and thoroughness of the RCT review. Specifically, the NRC team reviewed the licensee's CRs and NCRs. Additionally, the team reviewed external OE available on the internet (e.g., public open source literature) and non-public internal OE data bases available to the NRC staff. The NRC team did not identify any other similar examples of industry OE beyond what the RCT identified and based upon this review, the NRC team concluded that the RCT had considered relevant site and external OE necessary to identify a list of potential causes for the SB laminar cracking.

The NRC team also confirmed that the licensee had issued OE reports to alert the nuclear community to the Davis-Besse SB cracking phenomena. The team did not identify any issues of concern with the scope and content of these reports.

b.2.2 NRC Team Evaluation of the Potential Causes for SB Cracking

The RCT identified a list of 45 failure modes that could potentially contribute to the laminar cracking, either individually or in concert. The NRC team compared the potential causes for concrete cracking identified by the RCT to failure modes and environmental factors affecting concrete structures at nuclear power plants as discussed in two technical reports (NUREGs) produced by national laboratories for the NRC. Specifically, the NRC team reviewed the work performed by Brookhaven National Laboratory as documented in NUREG/CR-6927, "Primer on Durability of Nuclear Power Plant Reinforced Concrete Structures - A Review of Pertinent Factors." The objective of this report was to provide a primer on the environmental effects that can affect the durability of nuclear power plant concrete structures. The team also reviewed NUREG/CR-6424, "Report on Aging of Nuclear Power Plant Reinforced Concrete Structures," developed by Oak Ridge National Laboratory that included information related to aging factors and environmental stressors that can impact the performance of reinforced concrete structures. Based upon this review, the NRC team determined that the scope of potential failure modes affecting the SB as identified by the RCT was consistent with failure modes identified in these two NUREGs. Therefore, the NRC team concluded that

the RCT had appropriately applied OE to identify a comprehensive scope for potential failure modes that could contribute to or cause the SB laminar cracking.

The licensee contracted with vendors to perform examinations and tests of concrete CBS removed from the SB to gather information used to support or refute the 45 potential failure modes for the cracking. The NRC team observed or reviewed the results of these vendor tests/examinations conducted at offsite laboratories including: petrographic examinations, compression testing, splitting tensile strength testing, accelerated creep testing, and freeze-thaw testing. Specifically, the team observed the off-site vendor testing equipment and reviewed the process followed by:

- Vendor – (Photometrics) at the laboratory in California which performed petrographic examinations of the CBS from the SB in accordance with American Society for Testing and Materials (ASTM) C856, "Standard Practice for Petrographic Examination of Hardened Concrete," and ASTM C457, "Standard Test Method for Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete." The results of these examinations were used by the licensee to refute the potential failure mechanisms related to long term thermal stress cycles (e.g., freeze-thaw). Specifically, Photometrics examined 22 CBS using a scanning electron microscope for characteristics such as aggregate size, void fraction, concrete-to-reinforcing steel interaction, carbonation, and fracture analysis. The results of this testing determined that: the SB concrete was in good condition and consistent with the original mix design with no microcracks present on the fractured surfaces (e.g., no evidence of typical concrete time dependant thermal cycle failure modes), and the exposed concrete had carbonation typical for a concrete structure of 40 years. Additionally, the vendor confirmed that the outer surface of the CBS was not water-repellant and determined that the evidence suggested long term exposure to moisture which had migrating through the concrete.

- Vendor – (Performance Improvement International) at the University of Colorado Boulder Laboratory, which performed testing for internal relative humidity, compressive strength, splitting tensile strength, accelerated creep testing, and freeze-thaw testing. The NRC team noted the following:

    a. The internal relative humidity concrete tests measured (with embedded sensors) the distribution of internal moisture adsorbed in the CBS and no ASTM standard existed for this testing. The results from this testing was used to assess the potential for moisture intrusion into the SB wall.

    b. The compression testing of CBS was conducted in accordance with ASTM C-39 and was used to measure the compressive strength of the SB concrete. All concrete CBS tested had measured compressive strengths greater than the SB minimum design strength (4000 pounds per square inch (psi));

    c. Splitting tensile testing was conducted in accordance with ASTM C-496 to measure the SB concrete's tensile strength and all CBS tested had measured tensile strength higher than the minimum design (424 psi);

    d. The accelerated creep testing was conducted in accordance with ASTM C-512 to determine the susceptibility of the CBS to creep induced failures. Specifically, three types of creep behavior were evaluated under

this testing: 1) Basic creep – The long-term strain of concrete due to loading without drying and heating; 2) Drying shrinkage – The long-term strain of concrete due to drying without loading and heating; and 3) Drying creep – The long-term strain of concrete due to loading and drying without heating. Based on the results of this testing, the licensee's vendor subject matter experts confirmed that the effects of creep on the SB concrete was small and thus did not cause the SB laminar cracking; and

e. The freeze-thaw testing of concrete core samples was initiated and conducted in accordance with ASTM C-666. However, after the first day of testing, the temperature controller of the test machine failed and the test was halted until a new controller could be procured. The licensee decided not to continue or re-start the test, because the freeze-thaw testing was an extended long-term test, which would not have been completed in time to support the root cause investigation. Further, the RCT had relied on petrography examination results (e.g., lack of microcracks) to eliminate freeze-thaw as a potential cause for the laminar cracking.

The licensee contracted with vendor- Department of Interior (DOI) United States Bureau of Reclamation (USBR) - to perform measurements of CBS concrete thermal diffusivity, thermal conductivity, specific heat, and coefficient of linear thermal expansion. These tests were performed in accordance with the DOI standards USBR 4909-02, "Thermal Diffusivity of Concrete," USBR 4907-92, "Specific Heat of Aggregates, Concrete, and Other Materials," and USBR 4910-92, "Coefficient of Linear Thermal Expansion." The measured coefficient of thermal expansion was used as a material property in the analytical modeling performed by the licensee's vendor to validate the direct cause of the laminar cracking.

The licensee also contracted with vendors to perform analysis and modeling to support or refute failure modes such as, seismic; snow/ice; or dead weight of dome. The NRC team reviewed inputs, assumptions, and applications for analysis and modeling that supported the RCT conclusions as discussed below:

- The licensee's vendor developed a detailed three dimensional Finite Element Analysis (FEA) model using the Abaqus software for the structural analysis of the SB. The model included the SB shoulders so that an accurate representation and analysis of this SB feature of interest could be completed. This model was used to evaluate various loadings on the structure as described in the supporting vendor report. The vendor also developed a three dimensional finite element model using the Fluent Software. The model included the major structures adjacent to the SB to allow for the accurate assessment of their affects on this structure. This model was developed for computational fluid dynamics analyses, and it was used to evaluate various wind and thermal conditions acting on the SB. This model was used in several of the FENOC vendor's (Performance Improvement International) analysis exhibits. The NASTRAN analysis software was used to develop a three dimensional finite element model of the SB. This finite element model was used to evaluate transient thermal temperatures for the various environmental conditions.

- The vendor performed FEA to validate the three contributing causes of laminar cracking related to the configuration of the SB structural reinforcement (e.g., density and spacing of rebar, and the lack of radial reinforcement in flute shoulders). The vendor also performed FEA to refute three possible causes for the SB laminar cracking: (1) tornado wind; (2) long term thermal stress cycles; and (3) rebar creep. The results predicted insufficient radial stress to initiate or propagate laminar cracks. The NRC team confirmed that the vendor FEA model inputs used for these applications were adequately justified. The vendor identified five conditions necessary for SB laminar cracking. Two of the necessary conditions were: a significant amount of water has diffused into the concrete; and the environment temperature drops well below the freezing point of water so the temperature near the outer rebar mat behind the shoulders will drop below the freezing point of water. The vendor developed these inputs based on a documented evaluation of actual degradation of concrete water tanks, "Deterioration and Repair of above Ground Concrete Water Tanks in Ontario, Canada." The team reviewed this report and concluded that the FEA inputs postulated by environmental conditions during the blizzard of 1978 were credible.

The NRC team reviewed the RCR and supporting vendor report (Performance Improvement International - Root Cause Assessment Davis-Besse Shield Building Laminar Cracking) to evaluate if the RCT had sufficient evidence to refute all but six of the 45 potential failure modes. The six remaining unrefuted failure modes were used by the RCT to support the final identification of the direct, root or contributing causes of the SB laminar cracking (report Section b.4). The NRC team concluded that the RCT had established a sufficient basis to refute/exclude 39 of the 45 failure modes as potential causes for the SB cracking with one exception. The NRC team identified that the RCT had not recorded a sufficient basis in the RCR to eliminate slipform induced laminar cracking in the Failure Mode Analysis process. It is possible for concrete slipforming construction techniques to create subsurface cracking near the reinforcement material. This type of cracking is caused by excessive friction at the concrete surface in contact with the slipforms and can result in cracks not visible from the surface. (Reference -, "Slipforming of Vertical Concrete Structures - Friction between Concrete and Slipform Panel," by Kjell Tore Fossa - Department of Structural Engineering, The Norwegian University of Science and Technology N-7491 Trondheim Norway, June 2001). Excessive friction at the slipform/concrete interface can be attributed to a number of factors including speed (slow speed) and out-of-plumb conditions on the formwork. During original construction the licensee had identified an out-of-plumb condition associated with the slipform construction process. In response to the NRC team's questions, the licensee stated that information available on the out-of-plumb condition was limited to the original construction records which did not include information on the method of correcting the problem or if it caused excessive friction. However, the licensee determined that it was not probable that slipforming friction contributed to the observed cracking because the out-of-plumb condition peaked at three distinct elevations that did not correspond to the observed laminar cracking identified; the construction project specifications included considerations that reduce friction and the rate of slipforming (average about 4 ft per shift) was expected to be fast enough to minimize friction problems, and the observed cracking went through aggregate materials which indicated that the laminar cracking occurred after the concrete reached sufficient maturity and not during placement. The NRC team agreed with the licensee's explanation for why slipform induced cracking was not a possible cause for this event

and considered the licensee's failure to document this basis in the RCR as a minor documentation weakness (see report Section b.4).

b.3 Licensee Identified Causes of SB Laminar Cracking

The RCT members were supplemented by vendors (VATIC Associates, MPR, and Performance Improvement International) and utilized a collegial process with these vendors to arrive at conclusions documented in the RCR.

The RCT concluded that the Direct Cause for the SB concrete laminar cracking was the integrated affect of moisture content, wind speed, temperature, and the duration of these conditions created during the blizzard of 1978. The environmental conditions created by the blizzard of 1978 enabled moisture to penetrate the SB concrete, freeze and expand, which created radial stresses that exceeded the tensile strength of the concrete and initiated the subsurface laminar cracking (Attachment 2, Picture 11).

The RCT concluded that the Root Cause for the SB concrete laminar cracking was due to the design specification for construction of the SB (Davis-Besse Specification No. C-038, "Shield Building," Revision 1) that did not specify application of an exterior sealant from moisture. The other nuclear safety-related structures on-site had a protective sealant as a barrier against moisture migration into the concrete.

The RCT identified three Contributing Causes for the SB concrete laminar cracking:

- Stress concentration at the outer face of structural reinforcing steel behind the thickest section of the flute shoulder. The stress concentration behind the thickest section of the flute shoulder magnified the radial stress due to freezing/expansion of the moisture inside the SB wall creating a radial stress that exceed the tensile strength of the concrete and initiated a crack,

- Design did not include radial reinforcing steel ties or stirrups at intermediate spacing which enabled the laminar crack created by freezing moisture to propagate to the end connections, and

- Density of the structural reinforcing steel was less than or equal to six inch spacing in specific areas. Once a crack originated in the shoulder region, it continued to propagate into adjacent areas if a higher density of reinforcing steel was present such as at the top 20 feet of the SB and the mainsteam line penetration blockouts. The greater density of structural reinforcing steel enabled the laminar crack created by freezing moisture to propagate into these areas.

b.4 NRC Team Conclusions on Causes of SB Laminar Cracking

The NRC team evaluated the key factors and evidence developed in support of the causes identified by the RCT for the SB laminar cracking. The NRC team concluded that the licensee's RCT developed a sufficient basis to support the causes of the SB laminar cracking related to: the environmental factors created during the 1978 blizzard, the lack of an exterior moisture barrier, and the structural design elements of the SB. Specifically, the weather records, CBS results, IR testing and SB analytical modeling provided a sufficient basis to support the causes of the laminar cracking.

The NRC team reviewed the RCR, site root cause investigation procedures and interviewed licensee staff to evaluate if the causes for the SB cracking were adequately ascertained. The team concluded that the RCT was staffed with qualified and experienced staff supplemented by vendor subject matter experts with extensive experience related to concrete examination, testing and/or failure analysis. The NRC team confirmed that the RCT followed an approved site procedure and applied a scrutable process in conducting the root cause investigation.

The NRC team identified minor weaknesses in the RCR generally associated with the level of detail in the documentation recorded, but these weaknesses did not constitute performance deficiencies or findings because they did not adversely affect the outcome of the root cause process.

Additional details of the NRC team's review of this area are provided in Sections b.4.1 and b.4.2 below.

b.4.1 NRC Team Evaluation of Causes

The NRC team evaluated key factors that supported the Direct Cause - The integrated effect (on the SB) of moisture content, wind speed, temperature, and duration of these effects during the blizzard of 1978.

- The NRC team confirmed that weather records existed which supported the Direct Cause related to the extreme environmental conditions associated with the blizzard of 1978. This blizzard occurred from January 25 – 27, 1978, and produced rain with sustained winds, followed by rapid temperature drop and significant snowfall. Specifically, snowfall amounts ranging from 12 inches in Toledo to 22 inches at Saginaw, Michigan were recorded with wind speeds of 45 miles per hour (mph) and gusts to 105 mph west of Toledo, Ohio. This blizzard was preceded by a rapid drop in temperature beginning at 12 noon on January 25, 1978, and ending at midnight January 27, 1978. The vendor report included temperature maps that record a temperature drop from 40 degrees Fahrenheit (°F) at about 6:00 pm on January 25, 1978, to about -5° F by midnight. Daily temperatures were below 20° F by noon on January 26, 1978, and surface temperature continued to drop to near 0° F by midnight on January 27, 1978. These environmental conditions enabled moisture to penetrate the SB concrete, freeze and expand, which created a radial stress that exceeded the tensile strength of the concrete triggering the subsurface laminar cracking (Attachment 2, Pictures 10, 11 and 12).

- To confirm the Direct Cause, the RCT relied on a vendor developed finite element model to evaluate the thermal stress developed for a portion of the SB near the flute shoulders subject to moisture intrusion and freezing. The vendor model results confirmed that the radial stresses developed within the SB exterior wall were of sufficient magnitude to initiate the subsurface laminar cracking (Attachment 2, Pictures 11 and 12). A necessary component of this cracking process was the effect of wind-driven rain, which served to provide a constant source of moisture for penetration into the outer surface of the SB concrete wall (Attachment 2, Picture 10). The moisture at the exterior surface, saturated the pores in the outer layer of concrete with liquid water, and for some depth beyond created a high water vapor content within the concrete pores. The NRC team

reviewed the results of a moisture penetration test to evaluate the reasonableness of the licensee's assumptions on moisture intrusion into the SB wall. Specifically, a ponding test was conducted on a SB CBS concrete cylinder by the licensee's vendor at the University of Colorado Boulder. In this test, the concrete CBS cylinder was placed in an upright position with the outer surface facing up and moisture sensors were embedded in the concrete cylinder at different depths from the surface. A column of water was placed on top of the cylinder, and the depth of moisture penetration was measured to evaluate the resistance of the SB concrete to water and moisture penetration. Based upon this test, the depth of moisture penetration was about 2 to 3 inches after a few days of continuous exposure to water and this test was intended to simulate the continuous moisture presented by the wind driven rain that preceded the blizzard of 1978. Additionally, because the shoulder areas allow moisture to penetrate from two directions, a higher overall depth of moisture penetration would exist in the SB shoulder regions. The results of these moisture penetration tests supported the key assumptions applied by the vendors in the stress models developed to simulate the conditions that resulted in the SB laminar cracking. Therefore, the NRC team concluded that the RCT had developed a sufficient basis for the direct cause of the SB cracking.

The NRC team evaluated evidence that supported the Contributing Causes, the inherent stress concentration at the outer face of structural reinforcing steel behind the thickest section of the flute, the lack of reinforcing steel ties or stirrups at an intermediate spacing between each end of the flute reinforcing steel connection with the structural reinforcing steel, and adjacent areas such as at the top 20 feet of the SB with higher density of reinforcing steel that enabled the laminar crack created by freezing to propagate outside the flute shoulder area.

- The NRC team reviewed the IR mapping results (Attachment 2, Pictures 4 and 5) and SB drawings identifying the location and configuration of structural reinforcement (e.g., rebar) to determine if the extent of laminar cracking identified was consistent with the RCT conclusions that SB reinforcement design features contributed to the extent of cracking observed. The NRC team confirmed that the extent of cracking identified by IR testing results was consistent with the RCT identified Contributing Causes. However, the NRC team identified areas of laminar crack indications between SB shoulders 6 and 7 and above the mainsteam line penetrations which did not include sufficient IR test locations to link this area directly with cracked areas in the adjacent SB shoulder regions. The NRC team's observation related to a lack of IR coverage did not invalidate the theory for the Direct Cause of the cracking or the Contributing Causes because the extensive computer modeling and vendor CBS testing provided a sufficient basis to validate these causes. Specifically, five analyses were completed in support of the SB laminar cracking causes Freezing Failure and Rebar Spacing Sensitivity Study, Structural and Thermal Analysis Investigation, Stress State During 1978 and 1977 Blizzards, Stress Analysis Due to 105 mph Wind Load, and Laminar Cracking Due to 1978 Blizzard. Therefore, the NRC team concluded that the RCT had developed a sufficient basis for the Contributing Causes.

The NRC team evaluated the evidence which supported the Root Cause. Specifically, Davis-Besse Specification No. C-038, the design specification for construction of the SB, did not specify application of an exterior sealant from moisture.

- The NRC team reviewed design specification No. C-038, examined records for the CBS removed from the SB wall, and performed walkdowns of the SB exterior wall. Based upon this review, the team confirmed that the SB specification did not require a moisture barrier, no moisture barrier currently existed on the SB exterior surface and that the design standards and Code applicable to the SB construction (ACI-307, "Design and Construction of Reinforced Concrete Chimneys," and ACI-318, "Building Code Requirements for Reinforced Concrete") did not require installation of a moisture barrier. Because the Direct Cause of this event required moisture intrusion, the NRC team concluded that the RCT had identified a sufficient basis for the Root Cause involving the lack of a moisture barrier in the original SB construction specification.

- Because the SB did not contain a moisture barrier, the NRC team evaluated if the SB design was consistent with ACI-201.2R-01, "Guide to Durable Concrete." Specifically, for concrete that will be exposed to a combination of moisture and cyclic freezing ACI-201.2R-01 recommends design of the structure to minimize exposure to moisture, a low water to cement ratio, appropriate air entrainment, quality materials, adequate curing before first freezing cycle, and special attention to construction practices. For minimizing exposure to moisture, this ACI standard stated, "Because the vulnerability of concrete to cyclic freezing is greatly influenced by the degree of saturation of the concrete, precautions should be taken to minimize water uptake in the initial design of the structure. The geometry of the structure should promote good drainage. Tops of walls and all outer surfaces should be sloped. Low spots conducive to the formation of puddles should be avoided. Weep holes should not discharge over the face of exposed concrete. Drainage from higher ground should not flow over the top or faces of concrete walls." In this case, the SB design provided for a design that minimized uptake of moisture into the SB wall, but these measures were not effective at precluding the moisture intrusion associated with the 1978 blizzard event. Based upon the review of the SB design and the RCT investigation of original construction practices, the NRC team concluded that the original SB design was consistent with the recommendations for minimizing moisture intrusion as discussed in this ACI standard.

The NRC team determined that the lack of a SB moisture barrier was not a licensee performance deficiency and hence not an NRC finding or violation. Specifically, Inspection Manual Chapter 0612 defines a performance deficiency as, "An issue that is the result of a licensee not meeting a requirement or standard where the cause was reasonably within the licensee's ability to foresee and correct, and therefore should have been prevented." In this case, the licensee had met applicable standards (ACI-307, ACI-318) and regulatory requirements for construction of the SB without a moisture barrier. Further, the licensee could not have been expected to foresee (e.g., no prior nuclear industry OE) the unique combination of SB design elements and environmental conditions associated with the blizzard of 1978 that caused the subsurface cracking within the SB wall.

b.4.2 NRC Team Evaluation of the Root Cause Process

The NRC team evaluated the RCT investigation for adherence to the mandatory requirements identified in the licensee's root cause analyses procedure NOBP-LP-2011, "FENOC Cause Analysis." Specifically, the NRC team confirmed that the RCT had complied with the following mandatory aspects of this procedure:

Generic Implications - The evaluation of generic implications must include experience reviews and address extent of condition and extent of cause. The RCT documented their reviews in this area in the RCR with sufficient information to reach a conclusion regarding the potential for the Root Cause to affect other structures and processes.

- Qualified Root Cause Evaluator - The RCT must include a qualified root cause evaluator, and all the necessary resources and information must be provided in order for the RCT to complete the root cause evaluation and reach the appropriate conclusion. The NRC team confirmed that the RCT was staffed with a qualified root cause evaluator, qualified in accordance with: NOP-LP-2001, "Corrective Action Program," and CAP-JFGRCE-FEN, "Root Cause Evaluator Job Familiarization Guideline." The NRC team also interviewed RCT members to confirm sufficient resources were provided to support an adequate root cause investigation and evaluation.

- Root Cause Investigation Method - The root cause investigation was required to be performed using techniques defined in the procedure. As documented in the RCR, the RCT had applied the TapRoot® Methodology, Problem Solving and Decision Making, Equipment Apparent Cause Evaluation, Event and Causal Factors Charting, Barrier Analysis, Change Analysis and Fault Tree Analysis. These methods and techniques applied in the root cause investigation were approved for use in the licensee's Procedure NOBP-LP-2011.

- CA Plan - A CA plan was required to be established and documented in the RCR that addressed the identified causes and included actions to prevent recurrence. The RCT documented a CA Plan in the RCR and in the associated CR-2011-03346 which accomplished these requirements including due dates and CA owners. Additionally, the root cause evaluation CAs were reviewed and approved by members of licensee management as a part of the Corrective Action Review Board process as defined in procedure NOBP-LP-2008, "FENOC Corrective Action Review Board."

- Peer Review - The cause evaluation report was required to be peer reviewed by a cause evaluator qualified to the same level as the cause evaluation or higher. In this case, the peer reviewer for the SB RCR was required to be qualified at the root cause level, and the NRC team confirmed that the assigned peer reviewer was qualified as a root cause evaluator in accordance with: NOP-LP-2008, "Corrective Action Program and CAP-JFGRCE-FEN, "Root Cause Evaluator Job Familiarization Guideline."

Based upon this review, the NRC team confirmed that the RCT followed an approved procedure and applied a scrutable process in conducting the root cause investigation and that the RCT methodologies applied TapRoot® Methodology, Problem Solving and Decision Making, Equipment Apparent Cause Evaluation, Event and Causal Factors

Charting, Barrier Analysis, Change Analysis and Fault Tree Analysis were successful in identification of the causes for the SB laminar cracking.

The licensee's four member RCT was supplemented by three vendors with subject matter experts knowledgeable in concrete structure design, construction, examination, and modeling. The primary vendor, Performance Improvement International, produced a separate proprietary vendor report to document its investigation results titled, "Root Cause Assessment Davis-Besse SB Laminar Cracking." To confirm that sufficient expertise was applied to the root cause investigation, the NRC team conducted interviews and reviewed records of the education and experience possessed by the licensee's RCT and supporting vendor staff. These records confirmed that the licensee and vendor staff possessed advanced graduate degrees and had experience in concrete engineering, metallurgy, materials science, civil engineering, structural engineering, nuclear engineering, and construction engineering, respectively. Several members of the RCT also had many years of experience performing root cause evaluations related to nuclear power plant events including experience with the root cause evaluation for Crystal River Unit 3 delamination cracking event. Additionally, the vendor supporting the RCT had previously developed and applied sophisticated finite element models used to support the investigation and evaluation of the delamination related cracking experienced at Crystal River 3. Based upon this review, the NRC team concluded that the RCT composition was staffed with appropriately qualified licensee personnel supplemented by vendors staffed with leading experts in numerous engineering fields and with extensive experience in concrete examination, testing and failure analysis.

The NRC team identified minor weaknesses in the RCR generally associated with the level of detail in the documentation recorded, but these weaknesses did not constitute performance deficiencies or findings because they did not adversely affect the outcome (e.g., conclusions) of the root cause process. Specifically, the RCR did not include:

- A review to determine why the SB specification did not include a requirement for coating as was included in other SR buildings.

- An explanation for why six CBS existed with two laminar cracks at slightly different depths. These cracks were closely spaced at depths which correspond to the outer rebar mat area and the licensee vendor experts considered that this crack pattern may be the result of two different cracks overlapping (e.g., overlapped because two cracks came from different directions and did not link up).

- An explanation that weather had prevented measuring crack depths/widths at one CBS location and did not explain the cause of radial cracks identified in four CBS. The licensee believed the radial cracks were caused by shrinkage in some cases and by the core bore drilling process in other cases.

- An explanation that additional investigations and analysis had been completed by the vendor in support of failure Modes 1.5 and 2.11 associated with the density of rebar.

- A documented basis to eliminate slipform induced laminar cracking as a potential failure mode. Subsequent discussions with the licensee confirmed that this

failure mode was not a possible contributor for the SB cracking (see Report Section b.2).

- Sufficient IR test results to positively confirm that the SB shoulder configuration (e.g., structural discontinuity) was a necessary factor to exist for all areas exhibiting laminar cracking. Specifically, laminar crack indications existed between SB shoulders 6 and 7 and above the mainsteam line penetrations which did not have IR test results that definitively connected to areas of cracking identified at the SB shoulder regions (see Report Section b.4).

- The results of the RCT's walkdown to confirm that other site safety-related buildings were coated and the results of the RCT reviews of the Structures Monitoring Program records for other site safety-related buildings.

- A more complete basis for excluding the SB roof dome in the extent of cause review for the laminar cracking. The RCT had excluded the SB roof dome based upon the contributing causes associated with the unique design elements of the SB exterior wall. Because the SB dome was coated with a latex based coating, the presence of this moisture resistant coating could have provided a more complete basis for exclusion than just the contributing causes.

- The specific depths within the SB CBS where ettringite (crystal formation from sulfate reaction with calcium aluminates) was detected in the concrete pores. This examination confirmed that the outer surface of the cores was not water repellant, because the concrete air voids were lined with secondary deposits of ettringite and calcium hydroxide suggesting long-term exposure to moisture migrating through the concrete. The lack of detailed records recording depth from the SB surface that this mineral was detected did not affect the results associated with moisture penetration. Specifically, the vendor did not rely on this test alone to determine the depth of water penetration into the SB. Instead, other vendor tests were conducted to directly measure the depth of water penetration into concrete samples removed from the DB SB (see report Section b.4).

The licensee entered these NRC team observations into the CA system (Reference CR-2012-04177) and initiated a revision to the RCR and the supporting vendor report, "Performance Improvement International - Root Cause Assessment Davis-Besse Shield Building Laminar Cracking," to correct these issues.

b.5 <u>Licensee CAs for Causes of SB Laminar Cracking</u>

The licensee defined a Problem Statement - On October 10, 2011, a concrete crack was observed at the flute region of a temporary access opening in the SB wall.

In response to this Problem Statement and to address the extent of laminar subsurface cracking discovered, the licensee RCT developed the following CAs and preventative actions as documented in the RCR and identified below.

Extent of Condition

- CA No. 1 – Additional examinations (specific locations not yet defined) of the SB exterior wall.

- CA No. 2 – Issue engineering change package for additional SB CBS (specific locations not yet selected).

Direct Cause – Integrated effect of moisture content, wind speed, temperature, and duration from the blizzard of 1978.

- Direct Cause CA No. 1 – Testing program to investigate the steel reinforcement capacity adjacent to structural discontinuities.

- Direct Cause CA No. 2 – Engineering plan to re-establish design and licensing basis for SB.

- Direct Cause CA No. 3 – Issue site specific procedure for long-term monitoring of the SB laminar cracking (RCR defines a schedule).

Root Cause – Design specification for construction of the SB did not specify application of an exterior sealant from moisture.

- Root Cause Preventive Action No.1 – Issue engineering change package for SB exterior sealant system.

- Root Cause Preventive Action No. 2 – Implement engineering change package for SB exterior sealant system.

- Root Cause CA No. 3 – Update inspection procedure to include SB exterior sealant system.

Contributing Cause No. 1 - Inherent stress concentration in outer face of structural reinforcing steel behind the thickest section of the flute shoulder.

- No CA required because root cause preventive actions nullify impact.

Contributing Cause No. 2 - Design did not include radial reinforcing steel ties or stirrups at intermediate spacing between each end of the flute shoulder reinforcing steel connection with the structural reinforcing steel.

- No CA required because root cause preventive actions nullify impact.

Contributing Cause No. 3 - Density of structural reinforcing steel less than or equal to six inch spacing at the top 20 feet of the SB and at openings and penetrations.

- No CA required because root cause preventive actions nullify impact.

b.6 NRC Team Conclusions on CAs for the Causes of SB Cracking

The NRC team evaluated the CAs to address the causes of the SB cracking to determine if they were sufficient to prevent recurrence, and ensure the continued capability of the SB to perform the design safety functions (biological shielding, controlled release of annulus atmosphere under an accident condition, and

environmental protection of the CV). Specifically, the NRC team reviewed the CAs as documented in the RCR for the causes identified to determine if they would eliminate and/or mitigate the conditions that caused the laminar cracking or which could lead to growth of the existing laminar cracking. Based upon this review, the NRC team concluded that the CAs and preventative actions, if adequately implemented, would prevent recurrence of the laminar cracking in the SB.

The NRC review of the CAs to address the Direct Cause are ongoing as part of the Davis-Besse license renewal application (LRA) process. Based upon the RCT proposed CAs and ongoing NRC reviews of the Davis-Besse LRA, the NRC team concluded that the capability of the SB to perform the design safety functions would be assured. In particular, the NRC LRA reviews will include an evaluation of the proposed program for monitoring of the SB cracking.

The NRC team identified two examples where the scope of CAs to address the causes of the SB cracking was too narrow. The licensee had not proposed examinations to confirm a lack of subsurface cracking in other safety-related building structures with installed moisture barriers as a means to further substantiate the Direct Cause. A CA proposed for the Root Cause included updating a site procedure for periodic inspections of only the SB exterior sealant system instead of a broader action to include inspection of other safety-related buildings with moisture barriers. The licensee entered the NRC team's observations into the CA system and was considering actions to expand the scope of these CAs.

Additional details of the NRC team's review of this area are provided in Sections b.6.1, b.6.2 and b.6.3 below.

b.6.1 <u>NRC Team Evaluation of the Extent of Condition Related CAs</u>

The RCT had identified CAs that were limited to only the SB, because it was the only above-grade nuclear safety-related structure on-site designed by Bechtel during original construction that did not have a white cement Thoroseal finish for sealing exterior concrete surfaces. Further, the RCT determined that a waterproofing membrane was installed below-grade on the SB exterior and the SB dome lacked factors found in the flute shoulders such as the discontinuity stress concentration factor and high density reinforcing steel necessary for crack initiation and propagation. However, the effectiveness or durability of the moisture barriers applied to other safety-related building structures was not evaluated by the RCT. Given the importance placed upon the moisture barrier in preventing this type of laminar cracking, the NRC team considered the proposed scope of the licensee's CAs too narrow. Specifically, no actions were proposed to examine other safety-related building structures with installed moisture barriers to demonstrate a lack of subsurface cracking. Doing so, would provide additional substantiation of the Direct Cause. In response to the NRC team's observation, the licensee entered this condition into the CA system (Reference CR-2012-04178) and discussed development of additional IR testing and CBS of other safety-related buildings to confirm a lack of laminar subsurface cracking.

The NRC team performed a review to determine if the RCT had complied with the procedural aspects of NOBP-LP-2011, "FENOC Cause Analysis," for CAs to address extent of cause. Specifically, this procedure required an extent of cause evaluation for each identified Root Cause and the Direct Cause. The licensee performed an extent of

cause review as described in Section 6.3 of the RCR and concluded that the accessible exterior concrete surfaces of the SB should be sealed to prevent moisture penetration like the other nuclear safety-related structures on-site, and that the exterior of other nuclear safety-related structures should be examined to ensure the protective coating remains acceptable. Because the RCT had considered all the identified causes including the Contributing and Direct causes in arriving at this conclusion, they had complied with the procedure. The NRC team also confirmed that the licensee had assigned site staff (e.g., owners) to each extent of condition CA with reasonable due dates.

b.6.2 <u>NRC Team Evaluation of CAs for the Direct Cause</u>

The RCT proposed three CAs for the Direct Cause of the SB cracking (e.g., Integrated effect of moisture content, wind speed, temperature, and duration of these conditions during the blizzard of 1978). Specifically, the RCT proposed a testing program to investigate the steel reinforcement capacity adjacent to structural discontinuities, an engineering plan to re-establish design and licensing basis for SB, and to issue a site specific procedure for long-term monitoring of the SB laminar cracking.

To provide qualitative insights on the licensee's proposed methods for monitoring the SB, the NRC team applied the process for condition assessment described in Section 4 of NUREG-6424. Specifically, in Section 4 of NUREG-6424, "Report on Aging of Nuclear Power Plant Reinforced Concrete Structures," ORNL stated, "Condition assessment and management of aging in NPP concrete structures require a more systematic approach than simple reliance on existing code margins. What is required is the integration of structural component function, potential degradation mechanisms, and appropriate control programs into a quantitative evaluation procedure." Further, ORNL stated, "Four criteria are considered to be of importance in assessing the significance of various degradation factors to which nuclear power plant reinforced concrete structures can be subjected: (1) rate of deterioration; (2) capability for inspection and early detection of degradation; (3) repairability of the sub-element affected; and (4) ultimate impact of the degradation factor(s)." Based upon application of this process to the DB shield building degradation (cracks), the NRC team did not identify any additional inspection methods that should have been considered beyond what the licensee had proposed for monitoring of the SB laminar cracking.

The licensee's program for monitoring of the SB laminar cracking will be the subject of further NRC review as part of the Davis-Besse LRA process. Specifically, the NRC issued a request for additional information (RAI) No. B.2.39-13) (ADAMS Accession No. ML11333A3960), and the licensee provided site specific information related to the SB cracking including: plans to monitor the extent and thickness of SB cracks, and corrosion of the SB rebars over the long term, and the details of tests to determine the long term effect of the concrete cracks on the ability of the rebar to carry design loads. Therefore, the scope of the NRC review for this RAI will assess and evaluate the results from the licensee's Direct Cause CA No. 1 – Testing program to investigate the steel reinforcement capacity adjacent to structural discontinuities and Direct Cause CA No. 3 – Issue site specific procedure for long-term monitoring of the SB laminar cracking. For the Direct Cause CA No. 2, the licensee will develop an engineering plan to re-establish design and licensing basis for the SB. Hence, the licensee will meet their procedure requirements for addressing the Direct Cause (Reference NOBP-LP-2011, "FENOC Cause Analysis"). Based upon the proposed actions and ongoing NRC

reviews for this area, the NRC team concluded that the continued capability of the SB to perform the design safety functions would be assured. In particular, the NRC LRA reviews will include an evaluation of the program for monitoring of the shield building cracking. The NRC team also confirmed that that licensee had assigned site staff (e.g., owners) to each Direct Cause CA with reasonable due dates.

b.6.3 <u>NRC Team Evaluation of CAs for the Root Cause</u>

The RCT proposed two preventative actions and one CA for the Root Cause of the SB cracking (e.g., the design specification for construction of the SB did not specify application of an exterior sealant from moisture). Specifically, the licensee planned to issue and implement an engineering change package for SB exterior sealant system and to update an inspection procedure to include examination of the SB exterior sealant system.

The licensee's procedure NOBP-LP-2011, "FENOC Cause Analysis," required that these CAs be able to restore the condition to acceptable standards. The preventative actions proposed included development and implementation of an engineering change package for installation of an exterior sealant system for the SB. The engineering change process would result in an update for the SB specifications to include an external moisture barrier, and this action would restore the SB to an acceptable condition to prevent additional cracking created by moisture intrusion. Additionally, the licensee CA No. 3 provided for an inspection procedure for the SB exterior sealant system to ensure the continued effectiveness of the moisture barrier. Therefore, the NRC team concluded that these preventative and CAs, if properly implemented would preclude moisture intrusion and hence preclude recurrence of the conditions that caused the SB laminar cracking. The NRC team also confirmed that that the licensee had assigned site staff (e.g., owners) to each CA with reasonable due dates.

The NRC team identified that the CA No. 3 for the Root Cause – Update inspection procedure to include SB exterior sealant system was too narrow. For this CA, the licensee identified a need to update ENDP- 0511, "Design Guidelines for Maintenance Rule Evaluation of Structures," for periodic inspection of only the SB exterior sealant system instead of a broader action to inspect all safety-related buildings with moisture barriers. The licensee stated that they had intended this CA to include inspection of all safety-related buildings and not just the SB. To ensure this CA was properly implemented, the licensee recorded this NRC observation in CR-2012-04177.

b.6.4 <u>NRC Team Evaluation of CAs for the Contributing Causes</u>

The RCT identified that no CAs were necessary for the three contributing causes related to SB structural design elements because the Root Cause preventive action to install an exterior sealant system established a barrier against moisture intrusion and nullified the need for any CAs. Specifically, the RCT determined that the acute freezing and expansion of moisture in the SB concrete was the only scenario capable of producing radial stresses large enough to enable the laminar crack initiation. Based upon computer modeling of the SB loads without the moisture intrusion, the extreme combinations of temperature and wind were insufficient to result in laminar cracking of the concrete. Therefore, the RCT concluded that the Root Cause CAs nullified the impact of the contributing causes. The NRC team agreed with this conclusion, but believed a stronger basis could have been established by referencing/crediting the CA

for the Direct Cause CA No. 2 – Engineering Plan to Re-Establish the Design and Licensing Basis for the SB. Specifically, the scope of this CA would include an evaluation to determine what (if any) design changes to the SB are required to re-establish the design and licensee basis for the SB. The NRC team also confirmed that that licensee had assigned site staff (e.g., owners) to each CA with reasonable due dates.

The licensee assigned CAs for the Root and Direct Causes but not the Contributing Causes. The NRC team performed a review to determine if the lack of CAs assigned to the contributing causes complied with the licensee's procedure NOBP-LP-2011; "FENOC Cause Analysis." This procedure required that CAs shall be identified for all identified causes which are, "needed" to restore the condition to acceptable standards. The licensee identified that no actions were, "needed" for the contributing cause because the root cause preventive actions nullified the impact of contributing cause. Because no CAs were identified as, "needed" to restore the Contributing Cause conditions to acceptable standards, it complied with the site procedure.

c. Findings

No findings were identified.

4OA6 Meetings

.1 Exit Meeting

On May 9, 2012, the NRC team presented the inspection results to Mr. Barry Allen and members of the licensee staff at the exit meeting. The team reviewed proprietary documents during this inspection and asked the licensee to identify any report input material that was considered proprietary.

Attachment 1: Supplemental Information
Attachment 2: Photos and Diagrams

SUPPLEMENTAL INFORMATION

KEY POINTS OF CONTACT

Licensee

B. Allen, Site Vice President
B. Boles, Director, Site Operations
K. Browning, Root Cause Evaluator
K. Byrd, Director, Site Engineering
J. Hook, Manager, Design Engineering
D. Pace, Senior Vice President, Engineering
G. Wolf, Supervisor, Regulatory Compliance

Nuclear Regulatory Commission

D. Kimble, Senior Resident Inspector

LIST OF ITEMS OPENED, CLOSED AND DISCUSSED

Opened, Closed, and Discussed

None.

LIST OF DOCUMENTS REVIEWED

The following is a list of documents reviewed during the inspection. Inclusion on this list does not imply that the team reviewed the documents in their entirety but rather that selected sections of portions of the documents were evaluated as part of the overall inspection effort. Inclusion of a document on this list does not imply NRC acceptance of the document or any part of it, unless this is stated in the body of the inspection report.

Calculations and Evaluations

Corrective Action Records and Nonconformance Reports

CR-2011-03346; Fractured Concrete Found at 17M Shield Building Construction Opening; dated October 10, 2011

CR-2012-03889; Shield Building Core Bore S7-665-47; dated March 13, 2012

CR-2012-04177; Observations from NRC Inspection Shield Building Root Cause Report; dated March 19, 2012

CR-2012-04178; Observations from NRC Inspection Shield Building Root Cause Report; dated March 19, 2012

CR-2011-03232; Shield Building Reinforcement Bar Concrete Cover Less Than Drawing Requirement; October 8, 2011

CR-2011-01540; Exterior Shield Building Inspection Findings; September 2, 2011.

CR-G201-2009-68900; EVS Train 2 Failed Timed Drawdown Test Per DB-SC-03255; December 11, 2009

CR-2011-029663; 17M Annulus Sand Pocket Walkdown Results; October 4, 2011

CR-G201-2006-02932; Degraded Drain Piping Joint on Shield Building; August 3, 2006

CR-G201-2007-29203; CTMT Shield Building Exterior Surface Showing Evidence of Minor Degradation; October 25, 2007

CR-G201-2007-29204; CTMT Vessel Shield building Roof Drain Clogged; October 25, 2007

CR-G201-2008-33710; Groundwater In-seepage Identified in the Annulus Sandpocket; January 18, 2008

CR-G201-2009-68960; 50 percent of Containment Annulus Heaters Out of Service for an Extended Period; December 14, 2009

CR-G201-2010-72660; Groundwater Identified in the Annulus Sandpocket; March 4, 2010

CR-G201-2003-06445; Expansion Anchor Drilled Into Unsound Concrete; August 11, 2003

CR-G201-2002-07671; Cement Mortar Mix for Void Repair Material; October 4, 2002

CR-G201-2002-07472; Voids in the Containment Shield Building Annulus Side; September 24, 2002

CR-G201-2002-07080; Shield Building Concrete Voids; September 30, 2002

CR-G201-2002-04713; Shield Building Vertical Rebar Spacing Do Not Meet Specification; August 21, 2002

CR-G201-2002-04253; Shield Building Rebar Cover Tolerance Below Specification Limit; August 14, 2002

CR-G201-2002-03375; Areas of Interest Identified During Shield Building Inspections; July 19, 2002

CR-G201-2001-1269; Containment Building Concrete Spalling; May 14, 2001

NCR 57; Containment Concrete Placement, Pour No. 2; April 11, 1972

NCR 359; Concrete Keyway Poured in Inverted Position; June 25, 1973

NCR 382; Electrical Blockouts not insulated; August 6, 1973

NCR 407; Rebar Placement – Dowels omitted or broken off; October 17, 1973

NCR 415; Embedded Plates for Station Vent Stack Supports Not Placed According to Drawing; November 5, 1973

NCR 451; Pipe Sleeve Flanges for Penetration No. 40 Not Aligned; February 1, 1974

NCR 457; Pipe Sleeve Flanges for Penetration No. 39 Not Aligned; February 15, 1974

NCR 474; Penetration No. 40 and No. 33 Flange Placement; March 22, 1974

NCR 479; Penetration No. 40 Pipe Sleeve Flange Not Aligned; March 26, 1974

NCR 602; Reglet in Shield Building Not Placed According to Drawing; November 18, 1974

NCR 743; Two Dowels from Shield Building Penetration No. 80 Missing; August 11, 1975

NCR 772; Drawing Conflict for Shield Building Reinforcement Placement; September 19, 1975

Drawings

C-109; Shield Building Roof Plan and Details; Revision 6

C-110; Shield Building Roof Plan Wall Section and Details; Revision 6

C-111; Shield Building Wall Development; Revision 11

C-111A; Shield Building Exterior Developed Elevation; Revision 2

C-112; Shield Building Details; Revision 10

C-113; Shield Building Details; Revision 11

C-114; Shield Building Dome Framing Plan and Details; Revision 3

C-115; Shield Building Blockout Details; Revision 4.

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Bechtel Power and Industrial Division Technical Specification No. 7749-C-25; March 12, 1970

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Corrective Action Review Board Minutes; February 24, 2012

Corrective Action Review Board Minutes; February 21, 2012

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CTL Group Report; Impulse-Response (IR) Test Data and Core Log Sheets for Shield Building Wall at the Davis-Besse Nuclear Plant, Oak Harbor, Ohio; November 23, 2011

DB 0179-0; Davis-Besse Design Criteria Manual Pages III.A.4-1 and III. A.4-2; Revision 4

DBNPS Specification C-025, “Central Concrete Mix Plant,” Revision 1

DBNPS Specification C-026, “Forming, Placing, Finishing and Curing of Concrete,” Revision 3

DBNPS Specification C-027, “Construction,” Revision 7

DBNPS Specification C-038, “Shield Building,” Revision 1

File C-38; Intra-Company Memorandum; Subject: Shield Building Parapet Wall; August 15, 1976

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FSK-C-799; Concrete Repair on Parapet Wall of Shield Building; July 7, 1976

Golder Associates and W. M. Slater and Associates Inc. - Report to Ontario Ministry of the Environment; Deterioration and Repair of Above Ground Concrete Water Tanks in Ontario, Canada; September 1987

Interim Field Report No. 1; Shield Building Slipform Concrete Mix Design C2-SF-4; April 26, 1971

Interim Field Report No. 3; Shield Building Concrete Placement Contract; July 14, 1971

Interim Field Report No. 5; Containment Shield Building Out of Plumbness; July 26, 1971

LER 1978-017; Loss of Meteorological System; February 23, 1978

Material Rejection Report; Shield Building Concrete Mix C2-SF-1 Rejected; January 25, 1971

Material Rejection Report; 6 Cubic Yards of Shield Building Concrete Mix Rejected; January 26, 1971

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Performance Improvement International Report – Retensioning Analysis, Crystal River Unit 3 Containment; February 1, 2011

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R. Malm; Predicting Shear Type Crack Initiation and Growth in Concrete with Non-Linear Finite Element Method, TRITA-BKN. Bulletin 97, 2009, Royal Institute of Technology (KTH), Stockholm, Sweden; April 2009

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Procedures

CAP-TP9903; FENOC Training Plan; Root Cause Evaluator; Revision 6

CAP-JFGRCE_FEN; Root Cause Evaluator Job Familiarization Guideline; Revision 4

NOBP-LP-2011; FENOC Cause Analysis; Revision 13

NOBP-LP-2008; FENOC Corrective Action Review Board; Revision 10

NOP-LP-2001: Corrective Action Program; Revision 29

EN-DP-01511; Design Guidelines for Maintenance Rule Evaluations of Structures; Revision 0

NOP-LP-2006; Company Nuclear Review Board (CNRB); Revision 8

LIST OF ACRONYMS USED

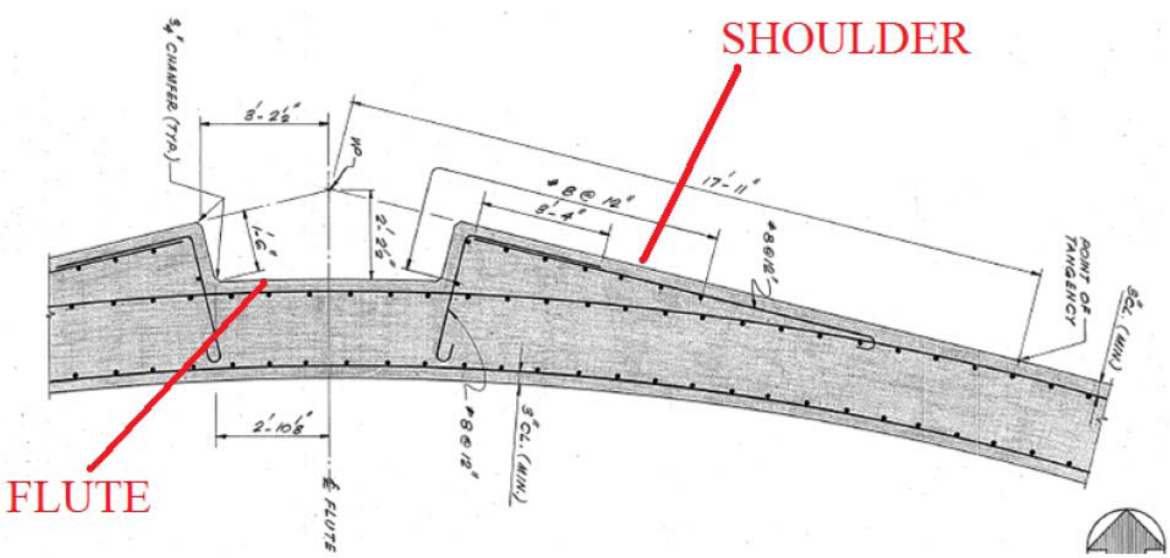
ACI	American Concrete Institute
ASTM	American Society for Testing and Materials
CA	Corrective Action
CAL	Confirmatory Action Letter
CBS	Core Boring Samples
CR	Condition Report
CV	Containment Vessel
DOI	Department of Interior
°F	Degrees Fahrenheit
FEA	Finite Element Analysis
ft	Foot
IMC	Inspection Manual Chapter
IR	Impulse Response
LRA	License Renewal Application
mph	Miles per Hour
NCR	Nonconformance Report
NRC	United States Nuclear Regulatory Commission
OE	Operating Experience
psi	Pounds per Square Inch
RAI	Request for Additional Information
RCR	Root Cause Analysis Report
RCT	Root Cause Analysis Team
SB	Shield Building
SDP	Significance Determination Process
USBR	United States Bureau of Reclamation

ATTACHMENT 2 – PHOTOS AND DIAGRAMS

Picture No. 1 – Davis-Besse Shield Building

Photos and Diagrams

Picture No. 2 – Davis-Besse Shield Building Flute and Shoulder Details

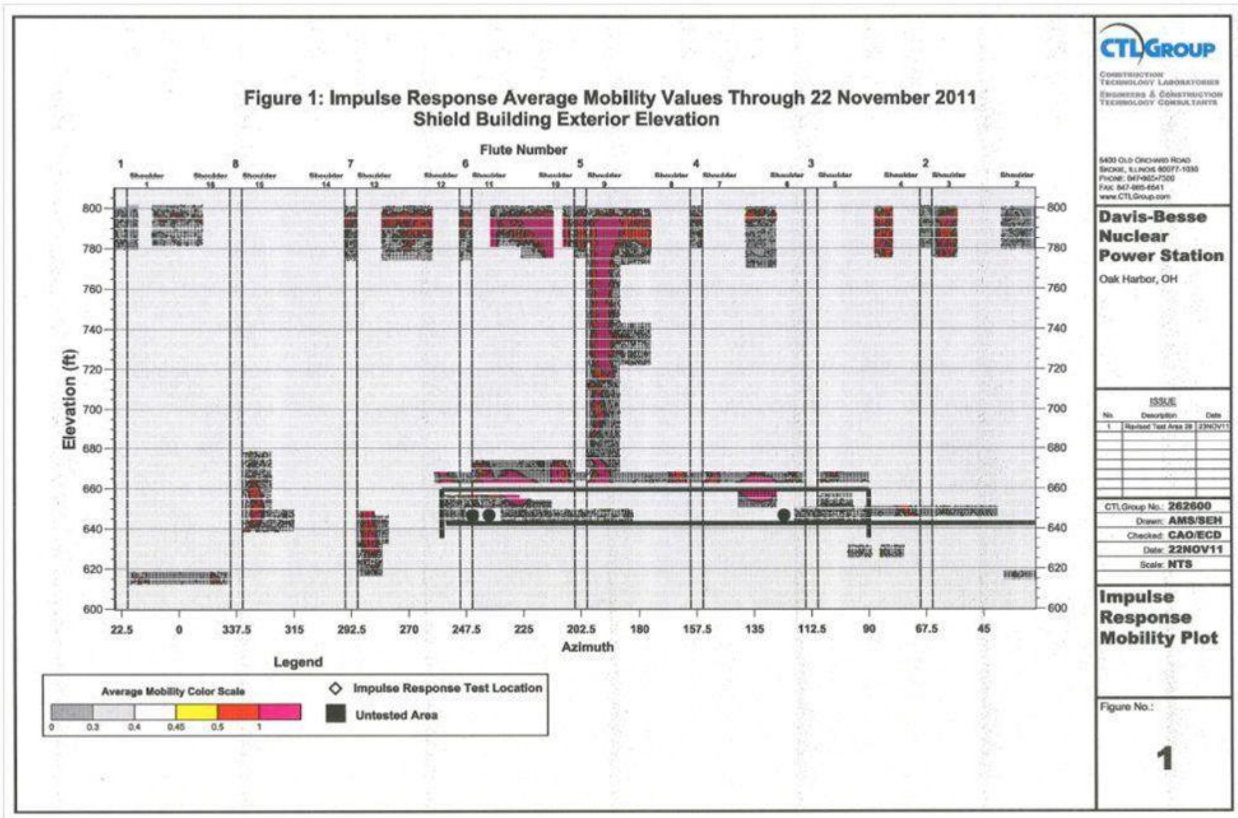


Photos and Diagrams

Picture No. 3 - Davis-Besse Shield Building Laminar Subsurface Cracking
(Note- initial condition after hydrodemolition to create an opening in the shield building and is included to show the relative location of subsurface laminar cracking. Based upon core bore samples, the crack condition (e.g., crack width) shown does not represent the laminar crack conditions in the sections of the shield building unaffected by the hydrodemolition process.)

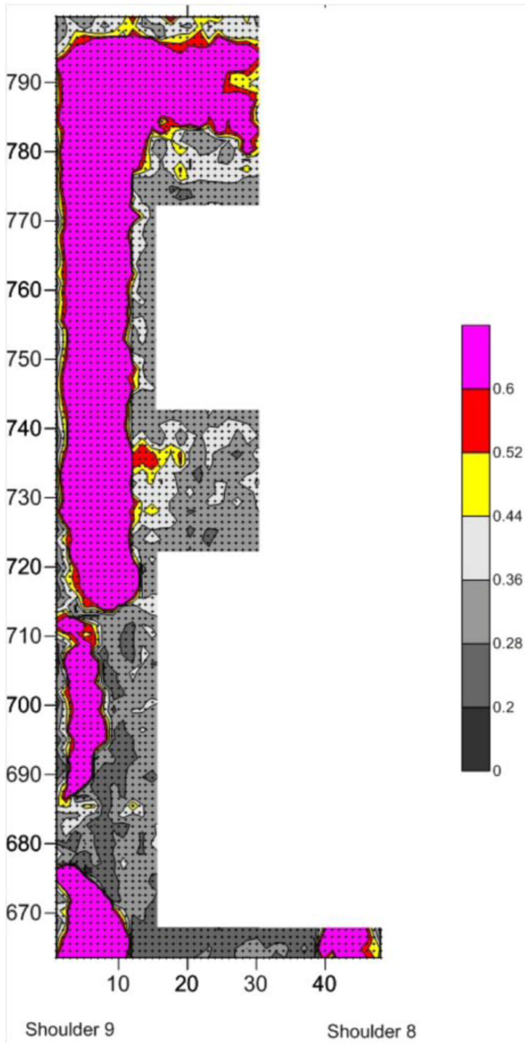
Photos and Diagrams

Picture No. 4 – Davis-Besse Shield Building Impulse Response Testing Mobility Plot



Photos and Diagrams

Picture No. 5 – Davis-Besse Shield Building Impulse Response Mobility Plot (Shoulder 9)



Photos and Diagrams

Picture No. 6 – Davis-Besse Shield Building Core Bore Location S7-667-25-2

Photos and Diagrams

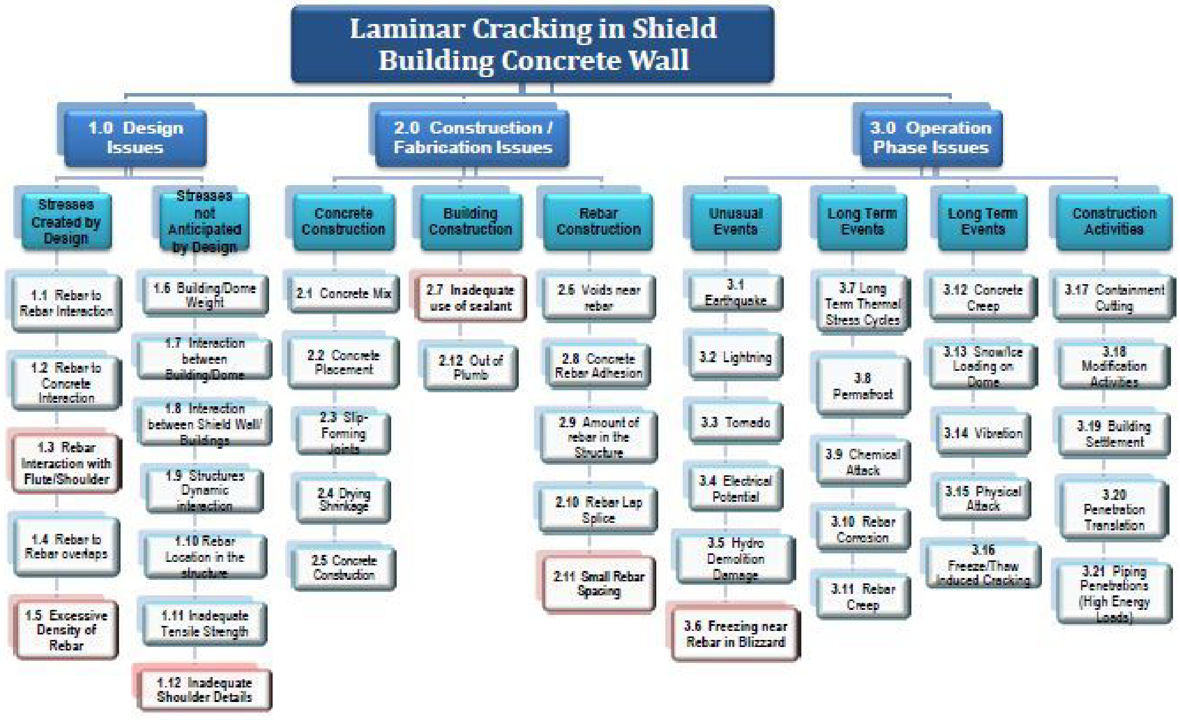
Picture No. 7 – Davis-Besse Shield Building Core Bore Location S11-663.75-30-10

Photos and Diagrams

Picture No. 8 – Davis-Besse Shield Building – Core Boring Sample

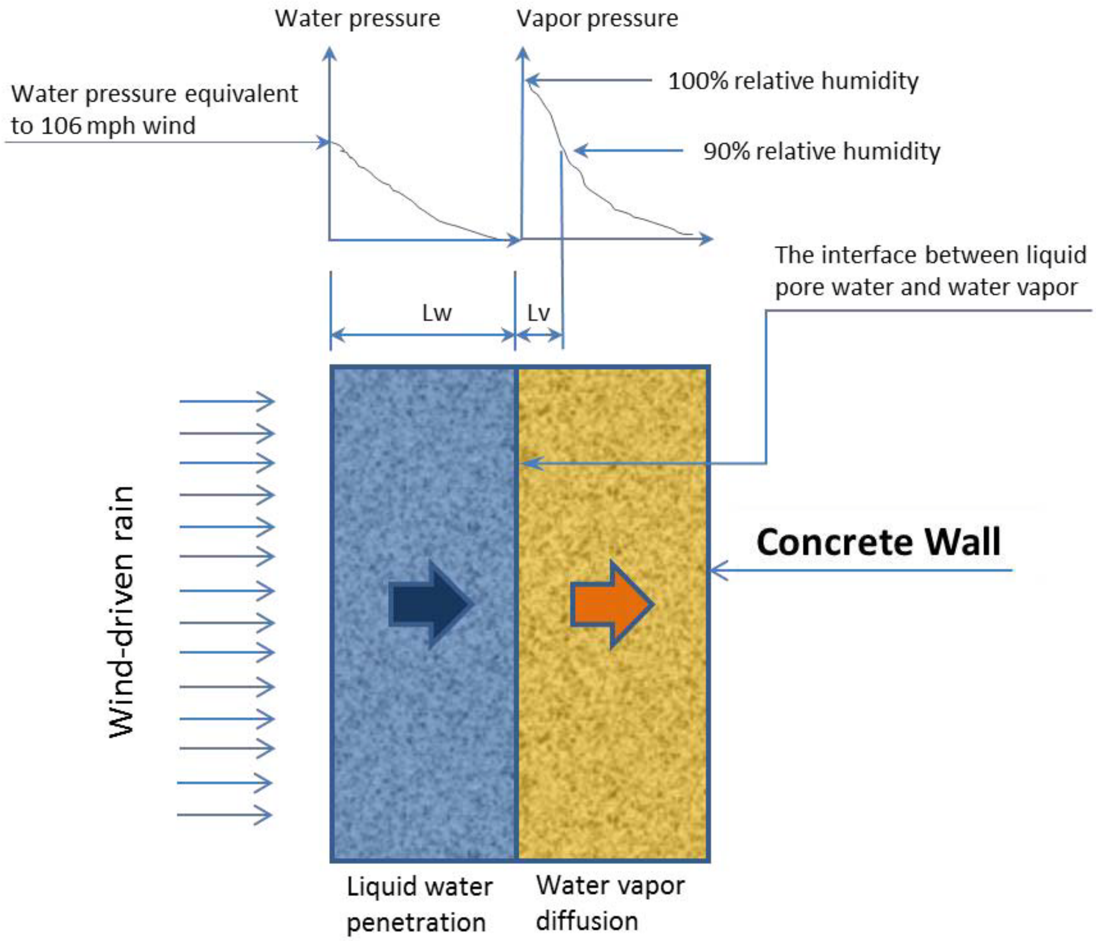
Photos and Diagrams

Picture No. 9 – Davis-Besse Shield Building Root Cause Analysis Report – Fault Tree



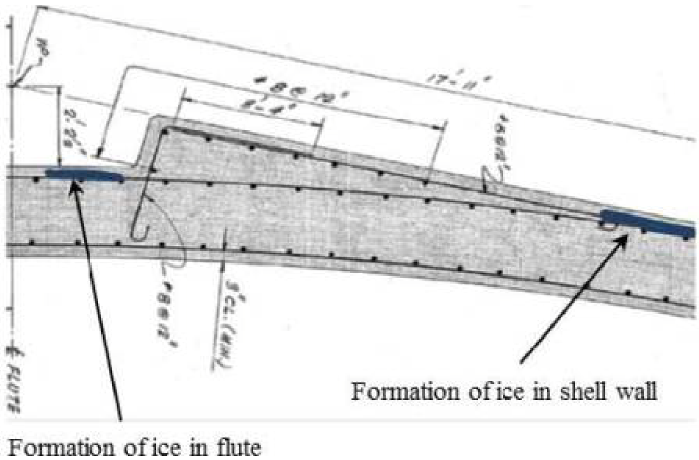
Photos and Diagrams

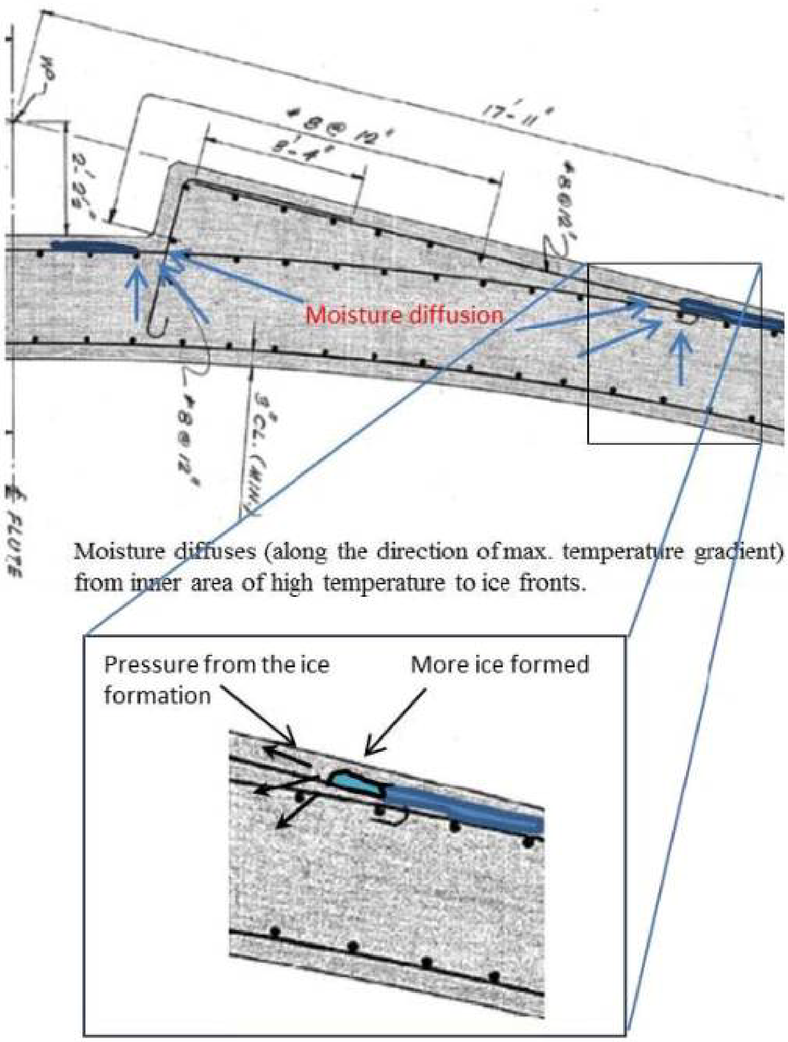
Picture No. 10 – Davis-Besse Shield Building – Water Migration



Photos and Diagrams

Picture No. 11 – Davis-Besse Shield Building – Location/Progression of Ice Formation

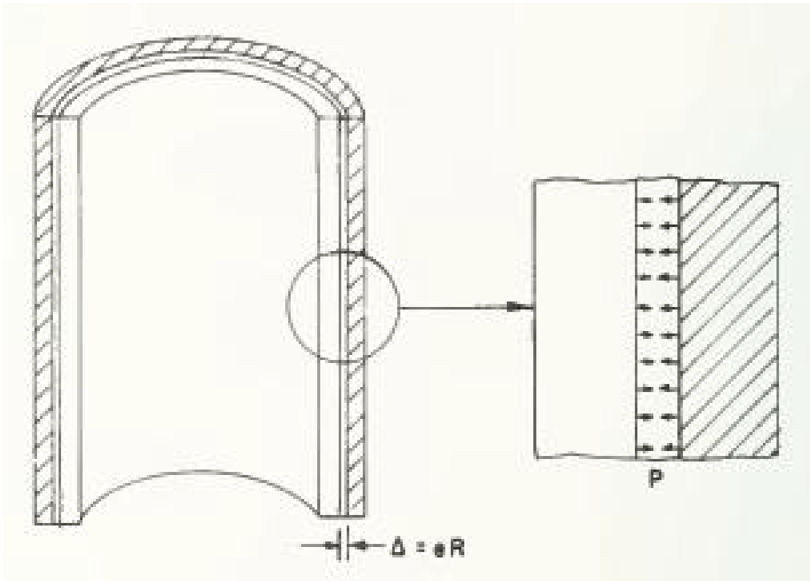




Progressive delamination of concrete cover near outer rebar mat due to ice formation

Photos and Diagrams

Picture No. 12 – Davis-Besse Shield Building – Subsurface Radial Tensile Stress



The NRC team also reviewed your corrective actions to address the causes of the shield building laminar cracking. The team identified two examples where the scope of your corrective actions to address the causes of the shield building cracking was too narrow.

- You had not proposed examinations to confirm a lack of subsurface cracking in other safety-related building structures with installed moisture barriers to further substantiate the Direct Cause.
- Your corrective action for the Root Cause included updating a site procedure for inspections of only the shield building exterior sealant system instead of a broader action to inspect all safety-related buildings with moisture barriers.

Your staff has entered the team's observations into the corrective action system, and we understand that you are considering actions to expand the scope of these corrective actions.

Additionally, the NRC has ongoing reviews as part of your Davis-Besse License Renewal Application that will evaluate your proposed program for monitoring of the shield building cracking. Overall, the team concluded that your corrective and preventative actions for the causes of the shield building laminar cracking, if adequately implemented, would prevent recurrence, and provide reasonable assurance for maintaining the shield building safety functions. The attached inspection report documents the inspection results for our review of your root cause evaluation activities and proposed corrective actions associated with your root cause report submitted to the NRC on February 28, 2012, (Reference ADAMS Accession No. ML120600056), and which were discussed with you and your staff at the exit meeting held on May 9, 2012.

Additionally, we have received and will review changes contained in Revision 1 of your root cause report (Reference ADAMS Accession ML12142A053) as part of our follow-up inspections planned for the shield building issue. As discussed with your staff, a public meeting will be scheduled in the near future to allow the opportunity for FirstEnergy Nuclear Operating Company to describe its root cause activities and planned actions going forward and NRC staff to discuss the related NRC inspection described in the enclosed report.

In accordance with 10 CFR 2.390 of the NRC's "Rules of Practice," a copy of this letter, its enclosure and your response (if any) will be available electronically for public inspection in the NRC Public Document Room or from the Publicly Available Records System (PARS) component of NRC's document system (ADAMS). ADAMS is accessible from the NRC Web site at http://www.nrc.gov/reading-rm/adams.html (the Public Electronic Reading Room).

Sincerely,
/RA/
Steven A. Reynolds, Director
Division of Reactor Safety

Docket Nos. 50-346
License Nos. NPF-3

Enclosure: Inspection Report 05000346/2012009(DRS)

Attachment 1: Supplemental Information
Attachment 2: Photos and Diagrams

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Letter to Mr. Barry Allen from Mr. Steven A. Reynolds dated June 21, 2012.

SUBJECT: DAVIS-BESSE NUCLEAR POWER STATION - INSPECTION TO EVALUATE THE ROOT CAUSE EVALUATION AND CORRECTIVE ACTIONS FOR CRACKING IN THE REINFORCED CONCRETE SHIELD BUILDING OF THE CONTAINMENT SYSTEM 05000346/2012009(DRS)

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