UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

ATOMIC SAFETY AND LICENSING BOARD

In the Matter of NEXTERA ENERGY SEABROOK, LLC (Seabrook Station, Unit 1)	Docket No. 50-443-LA-2 ASLBP No. 17-953-02-LA-BD01

Hearing Exhibit

Exhibit Number: NRC001

Exhibit Title: Staff Testimony

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NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

In the Matter of NEXTERA ENERGY SEABROOK, LLC (Seabrook Station, Unit 1)	Docket No. 50-443-LA-2

NRC STAFF TESTIMONY OF ANGELA BUFORD, BRYCE LEHMAN, AND GEORGE THOMAS

INTRODUCTION

Q.1. Please state your name, occupation, and by whom you are employed.

A.1a. My name is Angela Buford (AB).[1] I am a structural engineer in the Division of Engineering, Office of Nuclear Reactor Regulation (NRR), at the U.S. Nuclear Regulatory Commission (NRC). A statement of my professional qualifications is attached hereto, as Exhibit NRC002.

A.1b. My name is Bryce Lehman (BL). I am a structural engineer in the Division of Engineering, Office of NRR, at the NRC. A statement of my professional qualifications is attached hereto, as Exhibit NRC003.

A.1c. My name is George Thomas (GT). I am a senior structural engineer in the Division of Engineering, Office of NRR, at the NRC. A statement of my professional qualifications is attached hereto, as Exhibit NRC004.

Q.2. Please describe the nature of your responsibilities on behalf of the NRC.

[1] In this testimony, answers provided by specific witnesses are identified by denoting those witnesses' initials at the beginning of the answer. Where an answer is provided by all witnesses, the witnesses' initials are not provided.

A.2a. (AB) I am a structural reviewer and reactor technical reviewer responsible for planning, performing, and documenting safety evaluations of licensing requests (e.g., license amendment requests, license renewal and subsequent license renewal applications, etc.); implementing NRC regulations and requirements; and supporting NRC's reactor oversight activities. I provide technical and regulatory expertise in the structural engineering area to lead or support licensing reviews, operating experience reviews, topical or technical report reviews, inspection and enforcement activities, and development of regulations and regulatory guidance.

A.2b. (BL) I am a structural reviewer and reactor technical reviewer responsible for planning, performing, and documenting safety evaluations of licensing requests (e.g., license amendment requests, license renewal and subsequent license renewal applications, etc.); implementing NRC regulations and requirements; and supporting the NRC's reactor oversight activities. I provide technical and regulatory expertise in the structural engineering area to lead or support licensing reviews, operating experience reviews, topical or technical report reviews, inspection and enforcement activities, consensus codes and standards activities, and development of regulations and regulatory guidance.

A.2c. (GT) I am a senior structural expert and reactor technical reviewer responsible for planning, performing, and documenting safety evaluations of licensing requests (e.g., license amendment requests, license renewal and subsequent license renewal applications, etc.); implementing NRC regulations and requirements; and supporting the NRC's reactor oversight activities. I provide technical and regulatory expertise in the structural engineering area to lead or support licensing reviews, operating experience reviews, topical or technical report reviews, inspection and enforcement activities, consensus codes and standards activities, and development of regulations and regulatory guidance.

Q.3. Please explain what your duties have been in connection with the Staff review of the NextEra Energy Seabrook, LLC license amendment request (LAR) to revise the Seabrook Station, Unit No. 1 Updated Final Safety Analysis Report (UFSAR) (NRC007) to include a methodology to demonstrate that Seabrook structures with alkali-silica reaction (ASR) (also known as alkali-aggregate reaction (AAR)) continue to meet the design codes for original construction (INT010 (nonproprietary); INT011[2] (proprietary)).[3]

A.3a. (AB) I have been involved in the review of ASR at Seabrook since 2010, when the Staff became aware of the issue during its review of the Seabrook license renewal application (LRA). I am the primary technical reviewer for the LRA. In that role, I conducted the detailed review of NextEra's LRA that included the large-scale test program (LSTP) and a methodology for analysis of seismic Category 1 reinforced concrete structures affected by ASR at Seabrook. I was the primary author of the Staff's safety evaluation report (SER) for the LRA and I peer reviewed the Staff's safety evaluation (SE) for the ASR LAR. I supported the reasonable assurance determination for the LAR included as Enclosure 2 (nonproprietary version) and Enclosure 3 (proprietary version) of the letter dated March 11, 2019 that issued the ASR-related Amendment No. 159 to Facility Operating License No. NPF-86 for Seabrook (INT024 (nonproprietary); INT025 (proprietary)). During the Staff's detailed technical review of ASR at Seabrook, I participated in in-office audits, onsite audits, and field walkdown assessments of NextEra's implementation of its proposed method of evaluation of ASR-affected

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[2] The Staff does not cite Exhibit INT011 because it includes highlighting that is not a part of the original document.

[3] NextEra supplemented the LAR on September 30, 2016 (NRC010), October 3, 2017 (NRC013), December 11, 2017 (NRC014), and June 7, 2018 (NRC015). Separately, on May 18, 2018, in updating its license renewal application for Seabrook, NextEra provided revised versions of MPR reports previously submitted as LAR supplements (NRC016).

structures; the development of Staff requests for additional information (RAIs) and the evaluation of NextEra's responses; and public meetings with NextEra to discuss and resolve related issues. I also led one onsite audit of the LSTP at the Ferguson Structural Engineering Laboratory (FSEL) at the University of Texas at Austin, which was conducted as part of the review of the LRA (NRC017; NRC018). I was part of the technical reviewer team that conducted the review of the proposed aging management programs to manage the aging effects of ASR in the LRA. Since 2011, I have supported NRC Region I in several inspections of NextEra's actions, including those in response to the Confirmatory Action Letter (CAL) (NRC019), as well as biannual inspections at the FSEL during the LSTP, as part of the NRC's oversight of NextEra's actions to comprehensively address the ASR issue at Seabrook.

A.3b. (BL) I have been involved in the review of ASR at Seabrook since 2010, when the Staff became aware of the issue during its review of the Seabrook LRA. I am one of the primary technical reviewers for the LAR. In that role, I conducted the detailed review of NextEra's ASR LAR that included the LSTP and a methodology for analysis of seismic Category 1 reinforced concrete structures affected by ASR at Seabrook. I co-authored the Staff's SE that documented the Staff's finding of reasonable assurance for the ASR-related Amendment No. 159 to Facility Operating License No NPF-86 for Seabrook (INT024 (nonproprietary); INT025 (proprietary)). During the Staff's detailed technical review of ASR at Seabrook, I led in-office audits, onsite audits, and field walkdown assessments of NextEra's implementation of its proposed method of evaluation of ASR-affected structures; the development of Staff RAIs and the evaluation of NextEra's responses; and public meetings with NextEra to discuss and resolve related issues. I also participated in one onsite audit of the LSTP, which was conducted as part of the review of the LRA (NRC017; NRC018). I was part of the technical reviewer team that conducted the review of the proposed aging management programs to manage the aging effects of ASR in the LRA. I supported NRC Region I in several oversight inspections of NextEra's actions to comprehensively address the ASR issue at Seabrook.

A.3c. (GT) I am one of the primary technical reviewers for the LAR. In that role, I conducted the detailed review of NextEra's ASR LAR that included the LSTP and a methodology for analysis of seismic Category 1 reinforced concrete structures affected by ASR at Seabrook. I co-authored the Staff's SE that documented the Staff's finding of reasonable assurance for the ASR-related Amendment No. 159 to Facility Operating License No NPF-86 for Seabrook (INT024 (nonproprietary); INT025 (proprietary)). During the Staff's detailed technical review of ASR at Seabrook, I participated in in-office audits, onsite audits, and field walkdown assessments of NextEra's implementation of its proposed method of evaluation of ASR-affected structures; the development of Staff RAIs and the evaluation of NextEra's responses; and public meetings with NextEra to discuss and resolve related issues. I also participated in one onsite audit of the LSTP, which was conducted as part of the review of the LRA (NRC017; NRC018). I was part of the technical reviewer team that conducted the review of the proposed aging management programs to manage the aging effects of ASR in the LRA. Since 2011, I have supported NRC Region I in several inspections of NextEra's actions, including those in response to the CAL (NRC020), as part of the NRC's oversight of NextEra's actions to comprehensively address the ASR issue at Seabrook.

Q.4. What is the purpose of your testimony?

A.4. The contention proffered by the C-10 Research and Education Foundation (C-10) and supported by its expert, Dr. Victor Saouma, as reformulated and admitted by the Atomic Safety and Licensing Board,[4] has to do with the LSTP that NextEra commissioned MPR

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[4] *NextEra Energy Seabrook, LLC* (Seabrook Station, Unit 1), LBP-17-7, 86 NRC 59, 127 (2017) (LBP-17-7).

Associates (MPR), in collaboration with the FSEL, to conduct. The contention claims that the LSTP "yielded data that are not 'representative' of the progression of ASR at Seabrook [and that, a]s a result, the proposed monitoring, acceptance criteria, and inspection intervals are not adequate."[5] The purpose of our testimony is to explain (1) that the conduct of the LSTP provided reasonable assurance that its data are representative and/or bounding of the progression of ASR at Seabrook and (2) that NextEra appropriately used these LSTP data as a technical basis to develop the Seabrook ASR expansion monitoring program. Also, additional assurance of the continued applicability of the LSTP conclusions to Seabrook is provided by the future confirmatory actions required by the license condition that the Staff imposed as part of its approval of the LAR. Finally, our testimony rebuts the arguments made by Dr. Saouma in support of the contention. Our testimony is supported by the written testimony and affidavit of Jacob Philip (NRC005)[6] and the exhibits cited therein, which explains the separate, independent review of the LSTP by the NRC Office of Nuclear Regulatory Research (RES). Based on our and Mr. Philip's testimony, the Board should uphold the Staff's issuance of the requested license amendment, as conditioned.

BACKGROUND

I. ASR Generally

Q.5. What is ASR?

A.5. ASR is a chemical reaction that occurs in hardened concrete when there is reactive silica in the concrete aggregate, high-alkali cement pore solution, and moisture (typically approximately 80 percent or higher relative humidity). ASR produces an alkali-silicate

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[5] *Id.*

[6] The statement of professional qualifications for Jacob Philip is Exhibit NRC006.

gel that expands as it absorbs moisture, resulting in micro-cracking in the concrete after the gel fills voids, if any, in the concrete. The amount of cracking is dependent on the amount of gel and the geometry and reinforcement detailing of each structural member. The cracking degrades the mechanical material properties of the affected concrete.

Q.6. What are the mechanical material properties of concrete?

A.6. The mechanical material properties of concrete include compressive strength, tensile strength, elastic modulus, shear strength, and flexural strength. The compressive strength of a material, including concrete, is its capacity to withstand loads or stresses that tend to compress and reduce its size, as opposed to tensile strength, which is its capacity to withstand loads or stresses that tend to elongate and crack or split the material. The elastic modulus is the ratio of stress (force per unit area) to strain (ratio of change in length to the original length) in the elastic range of material behavior. The elastic range of a material is the range in which the material can be loaded and unloaded without permanent deformation, i.e., an elastic structure deforms when a load is applied and, when the load is removed, it returns to its original state. Shear strength is the ability of a material to resist a shear stress, which is created when two planes of the same object are trying to slide past one another. Flexural strength (or bending strength) is the ability of a structural member to resist a flexural load (moment), or the member's ability to resist bending when loaded.

The basic mechanical material properties of concrete (compressive strength, tensile strength, elastic modulus) are determined by testing standard-sized (e.g., 6 in. by 12 in. or 4 in. by 8 in., etc.) molded cylinders or drilled cores using American Society for Testing and Materials (now ASTM International) consensus standard procedures.

Q.7. What are the effects of ASR in a reinforced concrete structure in general and what are important considerations for addressing these effects?

A.7. ASR results in volumetric expansion that preferentially reorients in directions of lesser restraint and causes volume changes and cracking. The primary restraint or confinement to the expansion in the concrete is provided by the immediate reinforcement; additional restraint can also be provided by boundary conditions imposed by adjacent structural elements or structures and compressive loads. In other words, the presence of adjacent or attached structures can physically restrain the expansion. When expansion reaches a level of some significance, ASR can manifest itself in real structures as surface cracking, pop-outs (i.e., small conical fragments of concrete that break off from the structure), and displacement or deformation due to internal expansion of the concrete. Changes in cracking reflect internal expansions. With time, ASR can cause significant expansion, severe cracking, and differential movements in concrete components.

ASR expansion can affect structural performance, or a structure's capability to perform its intended function, by (1) reducing structural capacity, or the ability of the structure to carry loads, and (2) adding structural demand, or adding a load to the structure. Structural capacity can be reduced by the ASR cracking and possible reductions in material properties of the concrete. Structural demand can be added to the structure by an internal self-straining ASR load due to restraint to expansion from reinforcement, geometry, and boundary conditions causing deformation.

NRC regulations require licensees to demonstrate with reasonable assurance (not absolute assurance or zero risk, but, rather, a preponderance of the evidence) that ASR-affected structures or structural components remain capable of fulfilling their intended functions under design basis loads and load combinations (UFSAR, NRC007 § 3.8). To determine whether an ASR-affected reinforced concrete structure or structural component remains capable of fulfilling its intended functions, it is the structural strength (as a reinforced concrete composite system) that matters and not individual material strengths. The LSTP and the approach proposed by NextEra in its LAR addresses the effects of ASR on structural performance of affected structures in terms of structural strength of reinforced concrete structural systems or components, and not solely on the basis of individual concrete material strength properties.

In-situ reinforced concrete material properties (e.g., compressive strength, elastic modulus, shear strength, etc.) in ASR-affected structures are expected to be considerably better than material properties measured on cores that have been removed from the structure. This is because ASR causes micro-cracking and when a core is removed from a structure, the in-situ confinement that was provided by the reinforcement and the surrounding concrete (i.e., the structural context) is lost. Because of the in-situ confinement and the interaction between the reinforcing steel and the concrete, the load-carrying behavior of ASR-affected structures is generally expected to be better than would be expected from the material properties measured on test specimens or cores. Therefore, it is important that reinforced concrete structures affected by ASR be evaluated based on the impact on structural strength of a reinforced concrete composite system, and not necessarily on individual concrete material properties obtained by extracted core samples.

II. Discovery of ASR at Seabrook

Q.8. How did ASR occur at Seabrook and why was it not identified earlier?

A.8. The original concrete mix used at Seabrook unknowingly contained a coarse aggregate that was a potentially slow reactive aggregate. This was not identified during construction because the ASTM International (formerly American Society for Testing and Materials) standard screening tests approved and used at that time have since been determined to have limited ability to predict aggregate reactivity, especially for late- or slow-reacting aggregates. Because NextEra had assumed that its original cement and aggregate selection would preclude ASR development, it did not specifically inspect for ASR after construction.

Q.9. To your knowledge, has ASR been identified at any other U.S. nuclear power plant?

A.9. No.

Q.10. How was ASR discovered at Seabrook and what actions did NextEra and the Staff take in response to this discovery?

A.10. In June 2009, in preparation for its submission of a license renewal application for Seabrook, NextEra initially identified pattern cracking typical of ASR at Seabrook in the "B" Electrical Tunnel, and, subsequently, in several other seismic Category I structures. In 2010, during license renewal audit walkdowns, the Staff observed degradation in Seabrook concrete exposed to groundwater infiltration. To understand the impact of the groundwater infiltration on the concrete material properties, NextEra took drilled cores from affected concrete. Petrographic analysis of the cores confirmed the presence of ASR in concrete in below-grade walls of several Seabrook structures.

NextEra initiated prompt operability determinations to assess the safety significance of the issue and the basis for continued plant operation. The prompt operability determinations assumed that the Seabrook design code equations remained valid for concrete affected by ASR and used the most conservative loss of structural capacity for all applicable limit states. The reductions were overly conservative due to the lack of research results in the literature that were representative of the conditions and structures at Seabrook (e.g., reinforcement detailing, specimen size, etc.). As NextEra collected more information on the presence of ASR at Seabrook and incorporated revised analytical techniques, it revised the prompt operability determinations. In addition, in 2011, the Staff conducted three inspections of Seabrook that included reviewing NextEra's prompt operability determinations related to ASR-affected structures (NRC021; NRC022; NRC023).

On January 20, 2012, the Staff completed an inspection of Seabrook to assess NextEra's progress in the development of a corrective action plan and implementing schedule to address the ASR degradation issue (NRC024). NRC regional inspectors and headquarters experts[7] reviewed the operability determinations and found that (1) conservative load factors were used to ensure that there was sufficient margin to accommodate conservative loss of capacity, (2) field walkdowns confirmed no significant indications of deformation, distortion, or rebar corrosion, and (3) ASR was localized and occurring slowly based on existing operating experience and was being monitored. Therefore, the Staff concluded that, although Seabrook was not conforming with its licensing basis because ASR was not accounted for in the licensing basis, its ASR-affected structures remained capable of performing their safety functions. The Staff performed semi-annual inspections thereafter to ensure that this remained the case.

In 2012, the Staff issued a confirmatory action letter (CAL) (NRC019) to confirm commitments that NextEra had made to resolve the ASR issue with a bounding operability determination and interim monitoring that would be followed up by a long-term solution based on a large-scale test program. The Staff reviewed the plan for the proposed LSTP at FSEL and asked questions regarding how the testing program was being credited to analyze Seabrook structures. The LSTP was conducted from 2013 to 2016 and the Staff performed inspections of the LSTP to ensure that the results were being appropriately reflected in the operability assessments and evaluations of ASR-affected structures (NRC026; NRC027; NRC028;

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[7] George Thomas participated in this inspection.

NRC030; NRC032).[8] This led to NextEra developing, as part of the LAR at issue in this proceeding, an ASR expansion monitoring program.

Separately, during routine walkdowns in 2015, NRC resident inspectors observed seismic gaps and fire seals that appeared to have been degraded due to differential movement between adjoining concrete buildings (NRC031). It was determined that ASR had caused this additional aging effect through the cumulative effects of expansion and microcracking in ASR-affected structures. In addition, ASR microcracking had manifested as larger discrete cracking in some structures. These effects were not anticipated and were identified as the result of an effect of ASR that is separate from the expansion effect of ASR that had been addressed in the LSTP. That is, the LSTP did not address how building deformation would affect the ability of the structures to perform their intended functions. Therefore, NextEra developed an additional monitoring program, called the structure deformation monitoring program, to manage the effect of building deformation and included it as part of the LAR along with the ASR expansion monitoring program.

From 2010 to 2018, the Staff oversight of NextEra's response to the Seabrook ASR issue involved thousands of direct inspection hours by NRC regional inspectors and headquarters structural experts over the course of 20 inspections reviewing the ASR issue, including about 5 weeks of inspections (including one onsite audit (NRC018)) at FSEL on the LSTP from 2013 to 2015. For the inspection conducted as a follow-up to the 2012 CAL, the Staff's review was informed by a separate, independent review by Dr. Kent Harries, Associate Professor of Structural Engineering and Mechanics, University of Pittsburgh (NRC025).

[8] Angela Buford participated in all of these inspections. Bryce Lehman participated in one of these inspections. George Thomas participated in at least two of these inspections.

Table 1 – Inspection Reports

	Exhibit No.	Inspection Report	Date
1	NRC021	Integrated Inspection Report 05000443/2011002	May 12, 2011
2	NRC022	License Renewal Inspection Report 05000443/2011007	May 23, 2011
3	NRC023	Integrated Inspection Report 05000443/2011003	Aug. 12, 2011
4	NRC024	Inspection Report 05000443/2011010 Related to Alkali-Silica Reaction Issue In Safety Related Structures	Mar. 26, 2012
5	NRC025	Confirmatory Action Letter Follow-up Inspection - NRC Inspection Report 05000443/2012009	Dec. 3, 2012
6	NRC026	Confirmatory Action Letter Follow-up Inspection - NRC Inspection Report 05000443/2012010	Aug. 9, 2013
7	NRC027	Integrated Inspection Report 05000443/2013005	Jan. 30, 2014
8	NRC028	Integrated Inspection Report 05000443/2014002	May 6, 2014
9	NRC029	Integrated Inspection Report 05000443/2014003	Aug. 5, 2014
10	NRC030	Integrated Inspection Report 05000443/2014005	Feb. 6, 2015
11	NRC031	Integrated Inspection Report 05000443/2015002	Aug. 5, 2015
12	NRC032	Integrated Inspection Report 05000443/2015004 and Independent Spent Fuel Storage Installation Report No. 07200063/2015001	Feb. 12, 2016
13	NRC033	Inspection Report 05000443/2016008 Related to Alkali-Silica Reaction Affects On Safety-Related Concrete Structures And Notice Of Violation	May 6, 2016
14	NRC034	Integrated Inspection Report 05000443/2016002	Aug. 5, 2016
15	NRC035	Integrated Inspection Report 05000443/2016004	Feb. 8, 2017
16	NRC036	Integrated Inspection Report 05000443/2017002	Aug. 14, 2017
17	NRC037	Integrated Inspection Report 05000443/2017004	Feb. 12, 2018
18	NRC038	Integrated Inspection Report 05000443/2018001	May 14, 2018
19	NRC039	Integrated Inspection Report 05000443/2018011	Aug. 10, 2018

20	NRC040	Integrated Inspection Report 05000443/2018003	Nov. 13, 2018

These 20 inspections included a total of 9 findings related to ASR, one of which was cited as a notice of violation; all 9 findings were of very low safety significance.[9] The Staff also conducted five onsite audits at Seabrook, four of which specifically reviewed the Seabrook ASR expansion monitoring program (NRC0018; NRC041; NRC042; NRC043; NRC044).[10] The inspections of the LSTP, in particular, verified that NextEra and its contractors were adhering to the 10 C.F.R. Part 50, Appendix B, quality assurance requirements and the 10 C.F.R. Part 50, Appendix A, General Design Criterion 1. These inspections observed, on a sampling basis, the setup of the program and the facilities, fabrication and concrete pour, and testing of the specimens. The scope and findings of these inspections are documented in NRC Inspection Reports dated August 9, 2013 (NRC026), January 30, 2014 (NRC027), May 6, 2014 (NRC028), February 6, 2015 (NRC030), and February 12, 2016 (NRC032). During the inspections, the NRC inspectors did not identify any findings related to the LSTP and determined that the licensee implemented appropriate quality assurance program requirements. The Staff also completed an onsite audit of the LSTP at FSEL from October 27–29, 2015 (NRC017; NRC018).[11]

Staff oversight also involved, in July 2012, the creation of the Seabrook ASR Issue Technical Team (SAITT) consisting of Staff members from Region I, the Office of Nuclear

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[9] NRC021 (two findings of very low safety significance related to ASR); NRC023 (one finding of very low safety significance related to ASR); NRC025 (two findings of very low safety significance related to ASR); NRC038 (two findings of very low safety significance related to ASR); NRC029 (one finding of very low safety significance that, while not initially attributed to ASR, was ultimately determined to be related to ASR); NRC033 (one cited violation of very low safety significance related to ASR).

[10] All three Staff witnesses participated in at least three of these onsite audits.

[11] All three Staff witnesses participated in the FSEL onsite audit.

Reactor Regulation, and the Office of Nuclear Regulatory Research (NRC045).[12] The SAITT coordinated the onsite inspections, in-office technical reviews, and other evaluation and assessment activities associated with NextEra's resolution of the Seabrook ASR issue.

III. Addressing ASR at Seabrook

Q.11. How did NextEra attempt to address the issue of ASR at Seabrook and how did the Staff respond?

A.11. NextEra submitted the LAR in August 2016 and supplemented it in September 2016, October 2017, December 2017, and June 2018 in response to Staff questions as well as a public meeting with the Staff on August 24, 2017 (NRC046)[13] and two site visits held the weeks of June 5, 2017 (NRC043) and March 19, 2018 (NRC044).[14]

The Staff completed a draft SE for the LAR on September 28, 2018 (NRC047). The draft SE included an independent review of the LSTP by the NRC Office of Nuclear Regulatory Research (RES). RES reviewed Report MPR-4153, Revision 2 (NRC011 (nonproprietary); NRC012 (proprietary)), Report MPR-4273, Revision 0 (NRC008 (nonproprietary); NRC009 (proprietary)), and Report MPR-4288, Revision 0 (INT012 (nonproprietary); INT014 (proprietary)). Based on its review, RES concurred with NextEra's approach in general and suggested that NextEra corroborate the normalized elastic modulus-expansion curve on structures at Seabrook (which the Staff subsequently required as part of its license condition) (NRC005).

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[12] Angela Buford and George Thomas were contributing members of the SAITT. Jacob Philip was also a member of the SAITT.

[13] Angela Buford, Bryce Lehman, and George Thomas attended this meeting.

[14] Angela Buford, Bryce Lehman, and George Thomas attended both site visits.

Due to the first-of-a-kind nature of ASR in the U.S. nuclear industry, the Staff submitted the draft SE for additional review by the independent Advisory Committee on Reactor Safeguards (ACRS). The ACRS Plant License Renewal Subcommittee met with the Staff and NextEra and its consultants on October 31, 2018 specifically to "conduct a focused review of past, current, and future actions to address ASR at Seabrook" (NRC048 at 1). Based on this meeting and its review of the relevant documents, the ACRS concluded that

> 1. NextEra License Amendment Request 16-03 establishes a robust analytical methodology, supported by a comprehensive large scale test program, for the treatment and monitoring of alkali-silica reaction-affected Seismic Category I structures at Seabrook.
> 2. The NextEra license renewal application includes two new Aging Management Programs to monitor alkali-silica reaction and building deformation. These incorporate the test program results and license amendment request methodology and assure that the effects of alkali-silica reaction will be effectively tracked and evaluated through the end of the license renewal application period of extended operation.
> 3. The staff safety evaluations of the license amendment request and alkali-silica reaction-related Aging Management Programs in the license renewal application provide thorough assessments and findings. We agree with the staff's conclusion that NextEra's programs are acceptable (NRC048 at 1–2).

The ACRS also found that "[t]he LSTP test samples were highly representative of the ASR-affected structures at Seabrook" (NRC048 at 1–2 (emphasis added)). The ACRS noted that, although there were limited data available on the effects of ASR on highly constrained structures at the time of the discovery of ASR at Seabrook, since then a large body of ASR research similar to the LSTP is ongoing and that this research has "produced similar results to the LSTP" and has chosen "a similar approach of fabricating prototypical, structural-sized test samples, with concrete produced to artificially accelerate ASR" (NRC048 at 4). The ACRS commended the Staff's review of the LAR and LSTP as "deliberate and comprehensive" (NRC048 at 4).

Based on its review, as well as the independent reviews of RES and the ACRS, in March 2019, the Staff granted, with a condition, the LAR and provided the basis for this action in its comprehensive final SE (INT024 (nonproprietary); INT025 (proprietary)).

IV. The Seabrook ASR LAR

Q.12. Why was a license amendment needed to address the issue of ASR at Seabrook?

A.12. The design/construction codes that are part of the licensing basis for the Seabrook structures affected by ASR (i.e., American Concrete Institute (ACI) 318-71 for seismic Category 1 structures other than containment (NRC049) and Section III, Division 2, of the 1975 Edition of the American Society of Mechanical Engineers Boiler and Pressure Vessel Code (ASME Code, Section III, Division 2) for containment (NRC050)) do not account for the impacts of ASR. As a result, the prompt operability determinations concluded that the Seabrook ASR-affected structures were non-conforming with the current licensing basis. Therefore, NextEra needed to either change the Seabrook licensing basis to fit the current plant conditions or make changes to the current plant conditions to fit the existing licensing basis. NextEra elected to do a combination of these things through the LAR, which (1) makes specific modifications and supplements to the licensing basis design codes[15] and (2) establishes both an ASR expansion monitoring program based on the LSTP and a structure deformation monitoring program that ensure that the conditions at Seabrook remain within the licensing basis codes, as modified and supplemented, or ensure that physical changes (repairs or modifications) are made for cases where the amended licensing basis is not satisfied.

Q.13. How can ASR affect a reinforced concrete structure?

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[15] *See* INT024, encl. 2 at 38–46.

A.13. ASR can affect a reinforced concrete structure in two primary ways. First, cracking from ASR expansion can affect the structural capacity of the structural component or system, that is, the load carrying capacity for critical limit states such as flexure, shear, and compression. Second, cumulative expansion and cracking from ASR causes an internal self-straining load due to internal restraint (i.e., reinforcement) and/or external restraint (e.g., neighboring structures or structural elements, bedrock, etc.) that results in additional compressive stress in concrete and tensile stress in the steel reinforcement (i.e., ASR load) and can cause deformation of the structure.

Q.14. How does the LAR propose to address the two effects of ASR experienced at Seabrook?

A.14. The LAR proposes to address the effect of ASR expansion on structural capacity through an ASR expansion monitoring program based on the LSTP. This is evaluated by the Staff in Section 3.2 of the SE (INT024, encl. 2 at 6–31). The LAR proposes to address the effect of ASR on demand on a structure through a structure deformation monitoring program. This is evaluated by the Staff in Section 3.3 of the SE (INT024, encl. 2 at 32–33).

Q.15. Please describe the ASR expansion monitoring program.

A.15. Essentially, the ASR expansion monitoring program measures cracks in ASR-affected concrete, first in the in-plane direction using the crack indexing (CI) / combined crack indexing (CCI) method and/or pin-to-pin expansion measurements and then, when in-plane expansion reaches a specified threshold, in the through-thickness direction using the readings taken from a snap-ring borehole extensometer (SRBE) combined with a calculation of the through-thickness expansion that had occurred up to the time of the SRBE's installation. A CI is obtained by measuring and summing the crack widths along a set of perpendicular lines on the surface of a concrete element and normalizing the sum by the length of reference lines (typically reported in mm/m). The CCI is the weighted average of the CI in the two measured directions. Once a CI grid is set up, the same location is monitored over time and the CI values provide a quantifiable measurement of the state of cracking on the concrete member. Additionally, pins can be installed at the boundaries of CI grids for pin-to-pin expansion measurements.

The purpose of this monitoring is to ensure that the in-plane, through-thickness, and volumetric (the combination of in-plane and through-thickness expansions) expansions remain below the applicable ASR expansion limits for the structural limit states of shear, flexure, reinforcement anchorage, and anchors. These expansion limits are based on the expansion experienced during the LSTP. The interval for this monitoring is based on the progression of cracking—when there is no indication of pattern cracking or water ingress (i.e., Tier 1), the inspection frequency is as prescribed in the Seabrook structural monitoring program; when there are areas with pattern cracking that cannot be accurately measured or in-plane expansion of 0.05% (i.e., Tier 2), the inspection frequency is 30 months; and when there is in-plane expansion of 0.1% or more (i.e., Tier 3), the inspection frequency is 6 months. The Tier 3 in-plane expansion threshold of 0.1% triggers installation of the SRBE for through-thickness expansion monitoring and the initiation of a structural evaluation as part of the structure deformation monitoring program.

Various aspects of the ASR expansion monitoring program, such as the validity of using SRBEs for measuring through-thickness expansion, the point at which to transition from monitoring in-plane expansion to monitoring through-thickness expansion, the calculation of through-thickness expansion before the installation of SRBEs, and the ASR expansion limits below which code equations can be used to determine structural capacity, are based on data from the LSTP.

Additionally, the ASR expansion monitoring program includes a provision that it will consider future plant-specific or industry operating experience and research, including ongoing industry studies performed both nationally and internationally, to determine if there is a need to update the program (NRC016, encl. 2 at 23).

Q.16. Please describe the structure deformation monitoring program.

A.16. The structure deformation monitoring program addresses the additional ASR-induced structural demand (i.e., internal ASR load due to restraint to expansion and deformation) due to cumulative effects of ASR expansion and cracking, in combination with other design basis loads in load combinations described in the Seabrook UFSAR (NRC007 § 3.8). This program involves structure-specific analysis or evaluation using a three-stage process in which structures are screened for susceptibility to structural deformation caused by ASR and susceptible structures are subjected to an "analytical evaluation" or a "detailed evaluation," both of which involve the use of finite element models. The inputs to these models to define the ASR load are structure-specific in-plane expansion (CI/CCI or pin-to-pin measurements) measured at different locations of the structure near the time of evaluation and other structure-specific field measurements and observations, which are increased by a structure-specific threshold factor to account for potential future ASR expansion to the maximum level up to which the structural evaluation (code) acceptance criteria is met. The results of the demand forces (axial and shear forces, bending moments) from this analysis are compared to corresponding code-based structural capacity acceptance criteria. This structural analysis establishes threshold parameters and corresponding threshold monitoring limits for each structure and the structures are then monitored to ensure that the threshold monitoring limits are not exceeded and that code acceptance criteria remain satisfied. The structure deformation monitoring categories (i.e., Stages 1, 2, and 3), which represent the extent of refinement in the structural analysis, are distinct from the ASR expansion monitoring categories (i.e., Tiers 1, 2, and 3). In the structural evaluation, the original design load effects are supplemented with ASR load effects, while maintaining the level of structural performance implicit in the original design criteria and codes, to demonstrate that capacity is greater than or equal to load effects (i.e., demand).

V. The Structure Deformation Monitoring Program Is Outside the Scope of this Proceeding

Q.17. Does the process used in the structure deformation monitoring program rely on the LSTP?

A.17. No, the process used in the structure deformation monitoring program does not rely on the LSTP.

The structure deformation monitoring program does not rely on LSTP data as direct numerical input for the structural analysis to determine the structural demand under design basis loads including ASR. The LSTP provides the technical basis and expansion limits for using the code-based approach and the structural capacity acceptance criteria against which the structural demands are compared for applicable limit states; however, this does not influence the structural demands calculated by the structural analyses conducted as part of the structure deformation monitoring program.

NextEra's determination that, in general, ASR expansion in reinforced concrete imparts an additional compressive stress or load on the concrete in directions where expansion is restrained by the reinforcing steel (i.e., ASR load) is based on existing literature, although the results of the LSTP confirmed this. As part of the structure deformation monitoring program, the ASR load developed in this manner with respect to each ASR-affected structure at Seabrook is estimated based on field data from the actual structures and is not derived from the LSTP. Specifically, the structure deformation monitoring program uses CI/CCI (or baseline CI/CCI supplemented by pin-to-pin expansion measurements) to estimate the ASR strain in a concrete member. CI/CCI provides a quantitative assessment of the extent of cracking and is a commonly used conservative method for monitoring crack progression or in-plane expansion due to ASR, as discussed in ASR-monitoring specific guidance documents, such as the U.S. Department of Transportation Federal Highway Administration, "Report on the Diagnosis, Prognosis, and Mitigation of Alkali-Silica Reaction (ASR) in Transportation Structures" (FHWA Report) (NER013). This document also discusses CI/CCI supplemented by pin-to-pin expansion measurements. The structure deformation monitoring program may also use other appropriate field measurements (e.g., seismic gaps, annulus gaps, relative displacements, etc.) and observations using commonly used measurement tools.

The only overlap of the structure deformation monitoring program with the LSTP is that its use of code-based structural capacity acceptance criteria is tied to the point at which a structure would meet the expansion limits identified in the LSTP. However, the entire process used in the structure deformation monitoring program up to this point, including finite element analyses, are separate from the LSTP. Therefore, since C-10's contention has to do with the representativeness of the LSTP, the process used in the structure deformation monitoring program, such as the performance of finite element analyses, is outside the scope of this proceeding and only the limits that are shared between the ASR expansion monitoring program and the structure deformation monitoring program are at issue in this proceeding.

In conclusion, the LAR discusses two distinct programs to address two distinct effects of ASR at Seabrook and the contention only challenges portions of the ASR expansion monitoring program, which relies on LSTP data, and not the process used in the structure deformation monitoring program, which does not rely on LSTP data. C-10's contention did not raise issues related to the Building Deformation Assessment (which includes structural analysis) in LAR

Section 3.3 (INT010 at PDF 23–30) and related Structure Deformation Monitoring in LAR Section 3.5.2 (INT010 at PDF 33–34). Therefore, the following testimony focuses on the Staff's approval, with a condition, of the ASR expansion monitoring program. Although they are not within the scope of this proceeding, the following testimony, in an abundance of caution, also addresses C-10's arguments regarding the process used in the structure deformation monitoring program.

DISCUSSION

I. The ASR Expansion Monitoring Program Is Acceptable

Q.18. Why did the Staff find that the ASR expansion monitoring program proposed in the LAR was acceptable?

A.18. The Staff found that the ASR expansion monitoring program proposed in the LAR was acceptable because, in part, (1) the conduct of the LSTP provided reasonable assurance that its data are representative and/or bounding of the progression of ASR at Seabrook and (2) NextEra appropriately used these LSTP data to develop the Seabrook ASR expansion monitoring program. Also, additional assurance was provided by the license condition for future confirmatory actions that the Staff imposed as part of its approval of the LAR.

A. The LSTP Was Representative and/or Bounding

Q.19. Please describe the LSTP.[16]

A.19. The LSTP involved fabricating multiple large-scale concrete test specimens that were designed to represent and/or bound the behavior of reinforced concrete structures at Seabrook due to ASR. The test specimens were load tested to failure to evaluate the impact of

[16] *See* INT019-R, MPR-4273, Rev. 1 (nonproprietary); INT021, MPR-4273, Rev. 1 (proprietary); NRC008, MPR-4273, Rev. 0 (nonproprietary); NRC009, MPR-4273, Rev. 0 (proprietary).

ASR, in the structural context of a reinforced concrete component or system, on (1) the performance of expansion and undercut anchors installed in concrete (the Anchor Test Program), (2) the shear capacity of reinforced concrete (the Shear Test Program), and (3) the reinforcement anchorage of rebar lap splices (bond strength) and flexural strength and stiffness (the Reinforcement Anchorage Test Program). The LSTP also evaluated instruments and selected the SRBE for the measurement of through-thickness expansion (the Instrumentation Test Program). These three specific test programs were developed to address the areas where NextEra's initial analysis identified less margin, or where existing performance data were lacking. The Anchor Test Program used expansion anchors which were similar to the existing anchors installed at Seabrook after concrete placement and used undercut anchors to represent the anchors at Seabrook that were cast-in-place into the concrete. Undercut anchors are similar to cast-in-place anchors because both anchors use a positive bearing surface to transfer anchor load to the concrete (as opposed to expansion anchors which rely on friction between the anchor and the concrete).

Q.20. Why did the licensee conduct the LSTP rather than attempt to analyze the Seabrook ASR issue by other means?

A.20. The licensee evaluated the advantages and disadvantages of the LSTP versus harvesting specimens. It determined that the advantages of harvesting specimens are that the actual concrete from Seabrook is used and that ASR is allowed to develop naturally over a more slow and realistic timescale. It determined that the disadvantages of harvesting specimens are that cores more accurately reflect unreinforced structures, whereas Seabrook structures are reinforced concrete, that the harvesting process may damage the specimens, and that testing is limited to the ASR levels existing at the time of harvesting. It determined that the advantages of the LSTP are that it allows for the control of test variables, for testing beyond the ASR levels exhibited in Seabrook structures, for including the structural context of the reinforced concrete component or system, and for the use of test methods consistent with the test data that were relied upon in developing code provisions. It determined that the disadvantages of the LSTP are that it does not use the exact concrete from Seabrook and that ASR has to be developed much quicker than at Seabrook. Based on these determinations, the licensee concluded that the LSTP was the best means by which to develop the technical basis for the impact of ASR on structural performance to address the issue of ASR at Seabrook. The licensee's literature review also found that there were gaps in the literature on the impact of ASR on structural capacity for limits states of anchors, shear, and reinforcement anchorage (bond) in lap-splices specifically for structural components with 2-dimensional reinforcement with no through-thickness reinforcement, which is the typical reinforcement configuration of structural walls at Seabrook. Therefore, the licensee included in the LSTP specific programs to address these gaps.

Q.21. Does it matter to the Staff review that NextEra could have analyzed the Seabrook ASR issue in a different manner?

A.21. No. The Staff review involves evaluating whether the method proposed in the LAR (i.e., the LSTP) is one acceptable way to provide reasonable assurance (not absolute assurance or zero risk, but, rather, a preponderance of the evidence) that, with the license amendment, as conditioned, Seabrook will continue to meet NRC requirements and, if it is, the Staff approves the LAR or, if it is not, the Staff denies the LAR. Whether another method (e.g., harvesting) could have been "better" than the proposed LSTP method is not within the scope of the Staff's review.

Q.22. Please summarize the findings of the LSTP.

A.22. The LSTP found, in part, that ASR causes expansion of affected concrete that initially proceeds in all directions regardless of reinforcement (i.e., rebar) configuration. The two-dimensional reinforcement mats in the test specimens, that reflect the reinforcement mats at Seabrook, confined expansion in the plane of the reinforcement mats (i.e., the in-plane directions) after a certain expansion level. After this level, expansion was primarily in the through-thickness direction. Therefore, NextEra concluded that, up to this level of expansion, in-plane expansion measurements are sufficient and, afterwards, through-thickness expansion measurements are necessary. The LSTP used CI/CCI and pin-to-pin measurement for in-plane expansion measurement and found that SRBE is an acceptable method for through-thickness expansion measurement. The LSTP found that elastic modulus (the ratio of stress (force per unit area) to strain (ratio of change in length to the original length) in the elastic range of material behavior) is sensitive to ASR degradation and provides a repeatable correlation with through-thickness expansion that can be used to calculate through-thickness expansion prior to the installation of SRBEs. Other material properties were evaluated (compressive stress, tensile stress); however, the LSTP found that the reduction in elastic modulus provided the clearest correlation to through-thickness expansion.

For the Shear and Reinforcement Anchorage Test Programs, the LSTP determined that there was no adverse effect on structural limit states at the expansion levels tested, which were beyond the expansion levels seen at Seabrook. In other words, all of the tested specimens were able to exceed the strength capacities predicted by the code equations before testing failure. Therefore, NextEra used the lower of the highest through-thickness expansion levels tested in the Shear and Reinforcement Anchorage Test Programs, which was for shear, as the ASR expansion limit for the shear, flexure, and reinforcement anchorage structural limit states. For the Anchor Test Program, the LSTP found that anchor capacity is insensitive to through-thickness expansion and time of installation relative to ASR expansion. Therefore, NextEra set the ASR expansion limit for the anchors structural limit state to the greatest percentage of in-plane expansion that was tested without showing a reduction in anchor capacity. The LSTP also found that, within the expansion limits tested, the nominal structural capacity calculated using the design code equations and the minimum specified material properties provides a conservative structural capacity value (i.e., the calculated capacity was lower than the capacity demonstrated via testing).

Q.23. How did the overall conduct of the LSTP provide reasonable assurance to the Staff that its data are representative and/or bounding of ASR at Seabrook?

A.23. The Staff found that the conduct of the LSTP provided reasonable assurance that its data are representative and/or bounding of the progression of ASR at Seabrook for a number of reasons.

First, the Staff determined that the LSTP used test specimens that reflected the typical characteristics of ASR-affected structures at Seabrook. Specifically, the large size of the specimens represented the scale and structural context of structures at Seabrook and avoided uncertainties due to scaling effects associated with using smaller specimens. The Staff determined that the specimens were designed with reinforcement ratios and configurations similar to that at Seabrook. Specifically, they used a two-dimensional rebar mat in the in-plane direction to simulate the rebar in the face of the typical walls at Seabrook. This allowed the structural performance tests to account for the confinement effects provided by the typical Seabrook reinforcement configuration. The Staff determined that the specimen dimensions and rebar were also designed so that the specimens would best represent a part of a larger structure. Additionally, the Staff determined that the concrete of the specimens itself was made to reasonably reflect the properties of concrete in Seabrook structures. For example, the concrete mix design for the specimens was based on specifications used at Seabrook (e.g., compressive strength, coarse aggregate gradation and type, water-to-cement ratio, cement type, aggregate proportions) and, in part, included constituents for the concrete obtained from sources similar to those used during the construction of the plant. The Staff determined that these factors made the LSTP specimens much more representative of Seabrook structures than other existing ASR research, the vast majority of which has been conducted on small, unreinforced specimens.

Second, the LSTP data were obtained across a range of ASR levels that exceed and bound expansion seen to date at Seabrook and account for the effects of potential future expansion. Additionally, the Staff determined that the LSTP used a sufficient number of tests and specimens to provide reasonable assurance that its data were reliable.

Third, the LSTP used test methods and experimental designs consistent with the database of test data that was used to develop the ACI 318-71 (NRC049) (as well as the ASME Code, Section III, Division 2 (NRC050)) equations for concrete shear capacity (Report by ACI-ASCE (American Society of Civil Engineers) Committee 326 (NRC051)) and reinforcement anchorage and lap splice capacity (realistic beam splice specimen as illustrated in Figure 1.6(d) and explained in Section 1.2 of ACI 408R-03 (NRC052 at 6)). Additionally, the LSTP's test method and designs for anchor testing were consistent with the testing used by the vendor for original construction of the plant and the licensee response to the NRC demonstrating compliance with Inspection and Enforcement (IE) Bulletin No. 79-02, "Pipe Support Base Plate Designs Using Concrete Expansion Anchor Bolts," Revision 2 (IE Bulletin No. 79-02), which represents the plant design basis for anchor bolts (NRC053). The Staff determined that this similarity enabled a direct, representative comparison and assessment of the applicability and limitations of the code equations to determine the structural capacity of the range of ASR-affected Seabrook structures for the respective limit states.

Fourth, the LSTP established limits for through-thickness expansion and volumetric expansion, within which the Staff determined that the results of the LSTP would remain valid for Seabrook and against which the Staff determined that Seabrook structures can be monitored using similar monitoring methods as in the LSTP to ensure the validity of the LSTP results. The volumetric expansion is determined for Seabrook structures as the sum of measured in-plane expansion (CI/CCI or pin-to-pin) and through-thickness expansion (SRBE measurements) at the monitoring locations. The through-thickness and volumetric expansion limits were conservatively set at the maximum volumetric expansion observed on a test specimen from the Shear Test Program, which is more restrictive than the maximum seen in the Reinforcement Anchorage Test Program.

Fifth, in order to account for any potential observed differences in behavior in the future between ASR expansion in Seabrook structures as compared to ASR expansion in the test specimens, the Staff required, as a license condition, periodic confirmatory assessments of the ASR expansion behavior of Seabrook structures to ensure that it is similar to that observed in the LSTP. Any issues identified by these periodic assessments will be entered into the Seabrook corrective action program and addressed and will be subject to NRC oversight. The Staff determined that this provides additional assurance that the LSTP is representative.

1. The Anchor Test Program Was Representative and/or Bounding

Q.24. How did the conduct of the Anchor Test Program provide reasonable assurance to the Staff that its data are representative and/or bounding of ASR at Seabrook?

A.24. As explained above, the Anchor Test Program was performed consistent with the testing used by the vendor for original construction of the plant and the licensee response to the

NRC demonstrating compliance with NRC IE Bulletin 79-02, which represents the plant design basis for anchor bolts (NRC053). The program used Hilti Kwik Bolt 3 expansion anchors to represent post-installed, torque-controlled expansion anchors at Seabrook because they are similar to the Kwik Bolt 1 and 2 anchors that have been previously installed at Seabrook (i.e., design changes during the evolution of the bolt were minor) and because they are presently the preferred torque-controlled expansion anchor at Seabrook. All of the Hilti Kwik Bolt designs interact with the concrete in the same way and transfer load from the bolt to the concrete using the frictional resistance of the expansion wedge on the concrete. The program also used Drillco Maxi-Bolt undercut anchors to represent existing cast-in-place anchors and embedments because both anchor types use a positive bearing surface to transfer load to the concrete. Drillco Maxi-Bolt is the only undercut anchor used at Seabrook. Additionally, cast-in-place anchors may, unlike undercut anchors at full embedment depth, be able to transfer load through bond between the anchor shank and the surrounding concrete and, therefore, the use of undercut anchors to represent cast-in-place anchors is conservative. Based on industry standards and accepted practices for comparable evaluations, the path through which load is transferred from the anchor to the concrete is the primary consideration for representativeness among anchors (NUREG/CR-5563, “A Technical Basis for Revision to Anchorage Criteria” (March 1999) (NRC054); ACI 318-71 (NRC049); and ACI 349 Code Requirements for Nuclear Safety-Related concrete Structures and Commentary” (2013) (NRC055)). Since the selected anchors represent and/or bound the load-transfer mechanisms of anchors installed at Seabrook, the Staff found their use to be acceptable.

The Anchor Test Program was performed at various levels of ASR expansion, on anchors installed before and after ASR development, and using a range of anchor sizes and embedment depths consistent with the anchor population at Seabrook. The results were compared to results from prior to the development of ASR as well as to the calculated theoretical failure load. The program found that anchor performance is not sensitive to through-thickness expansion or time of anchor installation relative to ASR expansion and is not impacted up to in-plane expansion levels well beyond those currently seen at Seabrook; therefore, NextEra conservatively proposed to set the expansion limit for anchors at the lowest in-plane expansion level that showed reductions in capacity in the LSTP.

Because the Anchor Test Program provided a reasonable and/or bounding representation of the conditions at Seabrook, the Staff determined that it is acceptable for NextEra to assume no loss of anchor capacity if in-plane expansion remains below the limit identified during the program.

2. The Shear Test Program was Representative and/or Bounding

Q.25. How did the conduct of the Shear Test Program provide reasonable assurance to the Staff that its data are representative and/or bounding of ASR at Seabrook?

A.25. The Shear Test Program involved three-point bending tests (a test span supported at two points and a load applied at one point between the supports) of control and test specimens of differing levels of ASR. Consistent with ACI 318-71, the shear stress was normalized by the square-root of the measured 28-day concrete compressive strength (f'_c) and the shear capacity was defined based on the onset of diagonal cracking. All of the shear test results exceeded the shear capacity of the control specimens and the nominal concrete shear capacity (which was the lower bound capacity) calculated as $2\sqrt{f'_c}$ per Section 11.4.1 of ACI 318-71, indicating that there is no adverse effect of ASR on shear capacity at the expansion levels tested (NRC049 at 37). Therefore, NextEra conservatively set as the shear capacity expansion limit the highest level of ASR through-thickness expansion and volumetric expansion experienced in the shear test specimens.

The Staff determined that, because the Shear Test Program used representative specimens, used a large number of load tests to failure which were consistent with the applicable code, had test results that were all bounded by the strength calculated based on the ACI code provisions, had test results that were consistent and repeatable, and because the licensee will implement the future confirmatory actions required by the license condition, the expansion limit derived from the program is acceptable.

Similar results were reported in a recently published journal publication by Madhu M. Karthik, et. al, entitled "Experimental Behavior of Large Reinforced Concrete Specimen with Heavy ASR and DEF [delayed ettringite formation] Deterioration" (NRC056), in which a large-scale reinforced concrete specimen with heavy ASR/DEF deterioration was load tested to failure. The publication reports that the failure mechanism was brittle joint-shear failure and concluded that a comparison of the force-deformation results of the severely deteriorated specimen with the undamaged control specimen, and slightly and moderately ASR/DEF-deteriorated specimens, showed that there was no reduction in the load-carrying capacity and stiffness.

3. The Reinforcement Anchorage Test Program Was Representative and/or Bounding

Q.26. How did the conduct of the Reinforcement Anchorage Test Program provide reasonable assurance to the Staff that its data are representative and/or bounding of ASR at Seabrook?

A.26. The Reinforcement Anchorage Test Program was conducted to determine the effect of ASR on reinforcement anchorage, including lap splices, and on the flexural stiffness of reinforced concrete elements. The program involved four-point bending tests (loads applied at two midspan points and span supported at two end points) of control and test specimens of differing levels of ASR that each contained reinforcement lap splices at the center constant moment region. ASR did not result in any adverse effect on the reinforcement anchorage capacity. For all of the test specimens, the yield moment (applied moment at which the concrete reinforcement begins to yield) exceeded the theoretical value (M_y) and the flexural capacity exceeded the code-calculated nominal capacity (M_n). Additionally, all of the specimens were able to fully develop the minimum specified lap splice length and exhibited no reduction in flexural capacity. In fact, the results showed an increase in flexural capacity with an increase in ASR expansion over the levels of ASR tested. Therefore, NextEra conservatively proposed to set the expansion limits for reinforcement anchorage and flexure limit states to be the same as the shear expansion limit, which is less than the highest level of ASR through-thickness expansion and volumetric expansion experienced by the reinforcement anchorage test specimens.

The Staff determined that because the Reinforcement Anchorage Test Program used representative specimens and a large number of load tests to failure, because the results were consistent and repeatable, because flexure strength of test specimens exceeded that of the control as well as that of the nominal flexural capacity calculated based on the ACI code provisions, and because the licensee will implement the future confirmatory actions required by the license condition, the flexure and reinforcement anchorage expansion limits derived from the program are acceptable.

Similar results were reported in a recently published journal publication by M. Kathleen Eck Olave, et. al., “Performance of RC Columns Affected by ASR. II: Experiments and Assessment” (NRC057), which describes structural performance with regard to bond by load testing large-scale column specimens with lap splices and concentric axial loading affected by varying degrees of ASR. The publication concludes that the specimens with varying degrees of ASR showed no evidence of bond deterioration within the splice, had an increase in postcracking stiffness up to yielding, had an increase in yield strength, and showed no overall detrimental effects on the structural response when compared with control specimens without ASR deterioration.

4. The Treatment of Compression Was Representative and/or Bounding

Q.27. How did NextEra provide reasonable assurance to the Staff that the LSTP addressed compression in a manner that was representative and/or bounding of ASR at Seabrook?

A.27. As discussed above, the Reinforcement Anchorage Test Program data were representative of ASR at Seabrook. NextEra used these data to support the literature which provides that ASR expansion does not reduce the compression capacity of confined concrete in its structural context. Specifically, all Reinforcement Anchorage Test Program test specimens were able to develop the calculated flexural capacity, based on the specified concrete compressive strength, within the ASR expansion levels achieved during the testing. If compression capacity had been reduced at these ASR expansion levels, a compression zone failure would have occurred in the flexural specimens before the full flexural capacity was realized. Therefore, the Staff determined that the literature and the LSTP supported the conclusion that in-situ compressive strength of reinforced concrete members subject to axial compression, or combined axial compression and flexure, is not significantly affected by ASR when expansion remains within the expansion limits determined during the LSTP. Accordingly, the Staff concluded that it was acceptable for NextEra to use the originally specified nominal concrete compressive strength for Seabrook structures affected by ASR.

5. The Treatment of Reinforcement Fracture Was Representative and/or Bounding

Q.28. How did NextEra provide reasonable assurance to the Staff that the LSTP addressed reinforcement fracture in a manner that was representative and/or bounding of ASR at Seabrook?

A.28. NextEra evaluated the available literature regarding ASR and reinforcement fracture and identified examples in bend diameters smaller than is permitted by U.S. design codes. FSEL performed bend tests of reinforcing bars bent to the allowable limits of Seabrook design codes, ACI 318-71 (NRC049) or ASME Code, Section III, Division 2 (NRC050), and did not see evidence of compression crack formation. Based on this, NextEra concluded that ASR-impacted concrete constructed to ACI 318-71 (NRC049) or ASME Code, Section III, Division 2 (NRC050) standards at Seabrook is not susceptible to brittle fracture and, therefore, the failure mechanism was not addressed in the LSTP. The Staff found this acceptable because there has been no operating or experimental experience of reinforcement fracture due to ASR in structures designed to the design codes for Seabrook or other similar codes.

6. The Treatment of Seismic Response Was Representative and/or Bounding

Q.29. How did NextEra provide reasonable assurance to the Staff that the LSTP addressed seismic response and flexural stiffness in a manner that was representative and/or bounding of ASR at Seabrook?

A.29. The Staff reviewed Seabrook UFSAR Section 3.7(B) (NRC007) and noted that the smallest natural frequency of a seismic Category I structure is 4.0 Hz. The Staff also noted that the natural frequency of a structure is proportional to the square root of the stiffness to mass ratio. Based on a review of the LSTP data, the Staff noted that for heavily loaded structures (i.e., members with flexural cracking), the flexural stiffness increased as ASR expansion increased within the expansion levels tested. The Seabrook design-basis seismic ground response spectrum shows that seismic demands decrease for frequencies larger than approximately 3 Hz. Since all the structures at Seabrook have a natural frequency of at least 4 Hz, and since an increase in stiffness will increase a structure's frequency (considering no change in mass), it is reasonable to conclude that ASR will not have an adverse impact on seismic response for heavily loaded structures; therefore, the Staff found it acceptable for NextEra to conclude that the seismic analysis in the current licensing basis described in UFSAR Section 3.7 remains valid (NRC007).

For lightly loaded members (i.e., members with no flexural cracking), the test results showed a decrease in flexural stiffness. Based on the square root relationship between stiffness and natural frequency, this reduction could only lead to a minor reduction in natural frequency. The Staff noted that concrete is a heterogeneous material with variations in properties, which leads to uncertainties in material properties. To account for these uncertainties, modern concrete design includes inherent conservatisms, which are expanded upon in the Seabrook seismic design by using a +/-10% peak broadening in the response spectra. These inherent conservatisms would bound the reduction in natural frequency and, therefore, the Staff found it acceptable for NextEra to conclude that this reduction will not have a significant impact on the seismic response of the structure.

The Staff’s review further noted that, typically, the seismic response frequency of nuclear power plant structures depends on, and may be controlled by, the in-plane shear stiffness of regular structural walls or tangential shear for cylindrical walls, rather than by the out-of-plane flexural stiffness. In-plane shear stiffness is defined as a wall’s ability to resist deformation due to shear loading in the plane of the wall, as opposed to out-of-plane stiffness, which is related to the loads perpendicular to the surface, or plane, of the wall. Flexural stiffness is defined as a wall's ability to resist flexural deformation, or bending, in the direction perpendicular to the wall face (i.e., out-of-plane). The effect of ASR on the in-plane shear stiffness is expected to be comparable to the effect on flexural stiffness observed in the LSTP (i.e., an increase in stiffness and load carrying capacity relative to control specimens and the calculated service level). The in-plane stiffness (shear, flexure) of a structural wall is significantly higher than the out-of-plane stiffness because of the geometry, and thus the corresponding natural frequency in the in-plane direction will be further to the right of the peak of the response spectrum with lower seismic demand. Therefore, any further increase in frequency due to ASR effects is expected to also result in a decrease in seismic demand. Also, uncertainties in the impact of ASR on stiffness are expected to be accommodated by the 10% peak broadening of the response spectra.

The Staff's review of available literature related to the testing of scaled ASR-affected structural shear wall elements under in-plane lateral displacement excursions (lateral cyclic loading) and simultaneous axial load, simulating seismic loads, included a publication by F. Habibi, et. al. entitled "Alkali Aggregate Reaction in Nuclear Concrete Structures: part 3: Structural Shear Wall Elements" (Aug. 2015) (NRC058). This publication found that factors such as confinement and pre-stressing of reinforcement due to ASR expansion resulted in the ultimate capacity of the ASR shear wall test specimen being higher, but less ductile, than that of the shear wall control specimen. This is similar to what was observed with regard to out-of-plane shear capacity and flexural capacity in the LSTP. The Staff notes that the shear wall specimen tested in the publication only had a single layer rebar mat (versus two layers of rebar mats, one on each face, in a typical nuclear power plant wall) and that the compressive strength of concrete used was of the order of 10 ksi (high-strength concrete (less ductile) which is more than twice of that used in Seabrook structures). The amount of available vertical reinforcement plays an important role in determining the shear capacity of shear walls. In the Staff's assessment, these factors may have significantly contributed to the less ductile behavior observed in the reported shear wall tests; therefore, typical nuclear power plant walls are expected to perform significantly better with regard to ductility and energy dissipation capacity also. The Staff thus found it reasonable for NextEra to conclude that, within the levels of ASR tested in the LSTP, ASR does not have a significant impact on the seismic response of affected structures.

Of all of the Seabrook seismic Category 1 structures affected by ASR, the containment, which is protected from the external environment by the containment enclosure building, is of the least concern because: (1) ASR is indicated in only a limited portion of the containment wall in a small segment in the lower part of the annulus where infiltrated ground water had accumulated in the past and has been evaluated; (2) the containment is robustly designed in accordance with the ASME Code, Section III, Division 2 (NRC050), which uses the conservative working stress philosophy where stresses in the reinforcement are maintained below minimum specified yield strength under all primary design basis loads, including accident pressure and seismic loads; (3) the containment cylinder is heavily reinforced with orthogonal layers of rebars on each face in the meridional (vertical) and hoop (horizontal) directions to resist the membrane forces primarily from pressure and seismic loads (an additional orthogonal set of rebars inclined at 45 degrees is provided on the outside face to resist in-plane seismic shear forces and membrane tension from other loads; (4) near the base of the containment wall and at the spring line, radial inclined stirrups are also provided to resist radial shear; (5) the containment base mat, which is founded on bedrock, is heavily reinforced with orthogonal rebars on the top and bottom face and additional vertical and inclined shear reinforcement is provided to resist transverse shears under design accident pressure and seismic loads; and (6) the structural and leak-tight integrity of the containment are periodically verified by conducting periodic integrated leak rate tests (ILRTs or Type A tests) and local leak rate tests (LLRTs or Type B and Type C tests) under design basis accident pressure, pursuant to the requirements of Appendix J to 10 C.F.R. Part 50, "Primary Reactor Containment Leakage Testing for Water-Cooled Power Reactors." The historic results of these tests at Seabrook have not indicated concerns with containment structural or leak-tight integrity performance and such performance monitoring will continue, in addition to the containment inservice inspections, which are both required by the NRC's regulations, and are also identified as aging management programs required as part of the renewed operating license.

Based on all of these considerations, the Staff concluded that NextEra had provided reasonable assurance that the LSTP addressed seismic response and flexural stiffness in a manner that was representative and/or bounding of ASR at Seabrook.

7. The Instrumentation Test Program Provided Reasonable Assurance of Selection of Appropriate Instrument for Measuring Through-Thickness Expansion

Q.30. How did NextEra provide reasonable assurance to the Staff that the Instrumentation Test Program selected the appropriate instrument for measuring through-thickness expansion at Seabrook?

A.30. The Instrumentation Test Program evaluated, over a one-year period, three candidate instruments for measuring through-thickness expansion, a vibrating wire deformation meter (VWDM), an SRBE, and a hydraulic borehole extensometer, on a representative large-scale beam test specimen with regard to quality of data, ease of installation, and reliability (NRC008 § 5.4; INT019-R § 5.4). The Instrumentation Test Program determined that the SRBE was the best instrument because the instrument data agreed closely with the reference data, it directly measures the physical expansion and does not rely on additional equipment to function, it contains no electronics and does not require field calibration, it did not exhibit reliability problems, and it was easier to install than the VWDMs. Based on the test results, the Staff found it acceptable for NextEra to use SRBEs to measure future through-thickness expansion of Seabrook structures. The Staff notes that the SRBE provides a much more accurate and meaningful measure of through-thickness expansion than the subjective petrographic Damage Rating Index (DRI) method advocated by Dr. Saouma and discussed below (INT001-R at 31, 36).

8. The Measurement of In-Plane Expansion is Consistent with Industry Practice

Q.31. How did NextEra provide reasonable assurance to the Staff that CI/CCI was an appropriate method to use at Seabrook?

A.31. Unlike the measurement of through-thickness expansion, the measurement of in-plane expansion was not a subject of investigation at the LSTP. The LSTP first used visual methods because they are the recommended, standard industry inspection methods for routinely monitoring concrete structures to identify areas of potential structural distress or degradation, including degradation due to ASR. Once cracking was significant enough to reliably measure, the LSTP used CI/CCI and pin-to-pin measurements to measure in-plane expansion. The LSTP's CI/CCI expansion measurements were compared to corresponding pin-to-pin expansion measurements and found to compare very well. NextEra uses these same methods at Seabrook. CI/CCI provides a quantitative assessment of the extent of cracking and is a commonly used method for monitoring crack progression or in-plane expansion due to ASR, as discussed in ASR-monitoring specific guidance documents, such as the FHWA Report (NER013). This guidance document also discusses that CI/CCI supplemented by pin-to-pin expansion measurements is an even better monitoring approach (more accurate and more repeatable) for measuring in-plane ASR expansion.

In a solid structural component, crack movements reflect internal expansions. Cracking is always more pronounced on the free surface of a structure or component because that is where it is most free to develop and grow. It is understood that CI/CCI provides only an approximate estimate of in-plane ASR expansion because cracking on the surface due to ASR can also be influenced by other mechanisms such as temperature variation, drying and wetting cycles, shrinkage, or other factors. However, it provides a conservative estimate of in-plane expansion because all the cracking, with the exception of obvious structural cracks, are attributed to ASR regardless of the mechanism causing them; therefore, the Staff found that the use of the CI/CCI method as a method to measure in-plane expansion to date at Seabrook is appropriate and acceptable. Unless in-situ expansion monitoring was done from the time of construction (e.g., insertion of pins or other instrumentation during construction), the Staff is not aware of a practical method other than CI/CCI to estimate in-plane expansion-to-date when ASR is diagnosed many years after original construction. Once the baseline in-plane expansion-to-date is obtained using CI/CCI, pin-to-pin expansion measurements on the CI grid using DEMEC mechanical strain gauges provide an even more accurate method of monitoring the progression of in-plane expansion. This approach is also being implemented at Seabrook.

For these reasons, the Staff concluded that CI/CCI was an appropriate method to use at Seabrook.

B. NextEra Appropriately Used the LSTP Data to Develop the Seabrook ASR Expansion Monitoring Program

Q.32. Why did the Staff conclude that NextEra's use of the LSTP data to develop the Seabrook ASR expansion monitoring program was appropriate?

A.32. As discussed in the answers to the foregoing questions, the Staff determined that each aspect of the LSTP produced data representative and/or bounding of the effects of ASR at Seabrook. The Staff also determined that NextEra, in turn, used these data in a reasonable manner to develop aspects of the expansion monitoring program. For example, in order to calculate the total through-thickness expansion, it was necessary to develop a method for calculating the expansion that had occurred prior to the installation of SRBEs. To calculate this value, NextEra reviewed the LSTP data and determined that an empirical correlation between normalized elastic modulus and through-thickness expansion adequately predicts the amount of expansion due to ASR. A normalized property is the ratio of the concrete material property measured at different expansion levels (i.e., the time of testing for the beam specimen, or the time of SRBE installation for Seabrook structures) to that measured 28 days after fabrication or construction. NextEra reviewed the LSTP data, as well as literature data, and determined that reduction in concrete elastic modulus is more sensitive to ASR development than other properties such as compressive strength or tensile strength and, therefore, elastic modulus is the best parameter to use to estimate through-thickness ASR expansion. Using the test data, NextEra developed an equation to correlate normalized elastic modulus and through-thickness expansion. NextEra compared literature data to this equation and noted that the trend from the literature data compared favorably with the equation.

In order to obtain the normalized elastic modulus for application of the correlation equation to determine expansion to date of Seabrook structures, it is necessary to know the original (28-day) modulus of the impacted Seabrook concrete; however, elastic modulus was not measured during Seabrook construction. Therefore, NextEra provided two approaches by which the original elastic modulus could be determined—(1) use the equation from ACI 318-71, Section 8.3.1 (NRC049 at 22) to estimate the modulus based on the measured 28-day compressive strength or (2) use reference Seabrook cores representative of original construction and not impacted by ASR. Because both approaches can introduce uncertainty, NextEra applied a reduction factor to the normalized modulus term of the correlation equation, which would conservatively result in overestimating the to-date expansion in Seabrook structures.

The Staff determined that, based on considerations of statistical measures of goodness of fit, the correlation equation's coefficient of determination is reasonable because it accounts for a large majority of the variance in the LSTP data, as well as similar trends seen in the existing literature data. However, since the correlation curve had not been previously corroborated in-situ on ASR-affected structures in the field, the Staff included as a license condition a confirmatory corroboration study of the curve on Seabrook structures to provide additional assurance of the continued applicability of the curve. Based on these considerations and the addition of the normalized modulus reduction factor, the Staff found NextEra's proposed method for determining through-thickness expansion to date to be acceptable.

NextEra also used LSTP data to set the ASR expansion limits for the structural limit states at the lower of the highest in-plane, through-thickness, or volumetric, as appropriate, expansion level experienced in the Shear and Reinforcement Anchorage Test Programs of the LSTP. NextEra conservatively set the point at which to move from measuring in-plane expansion to measuring through-thickness expansion at Seabrook (i.e., the point at which expansion moves preferentially from the in-plane direction to the through-thickness direction) at approximately 0.1% expansion, which corresponds to a low level of ASR degradation as determined by the LSTP. The Staff determined that these applications of the LSTP data were also acceptable.

C. Staff-Required License Condition Provides Additional Assurance

Q.33. Why does the Staff-required license condition provide additional assurance that the LSTP was representative and/or bounding and that NextEra appropriately used the LSTP data to develop the Seabrook ASR expansion monitoring program?

A.33. The Staff-required license condition states:

> The licensee will perform the following actions to confirm the continued applicability of the [LSTP] conclusions to Seabrook structures (i.e., that future expansion behavior of ASR-affected concrete structures at Seabrook aligns with observations from the [LSTP] and that the associated expansion limits remain applicable). The licensee shall notify the NRC each time an assessment or corroboration action is completed.
>
> a. Conduct assessments of expansion behavior using the approach provided in Appendix B of Report MPR-4273, Revision 1 (Seabrook FP#101050), to confirm that future expansion behavior of ASR-affected structures at Seabrook Station is comparable to what was observed in the [LSTP] and to check margin for future expansion. Seabrook completed the first expansion assessment in March 2018; and will complete subsequent expansion assessments every ten years thereafter.
>
> b. Corroborate the concrete modulus-expansion correlation used to calculate pre-instrument through-thickness expansion, as discussed in Report MPR-4153, Revision 3 (Seabrook FP#100918). The corroboration will cover at least 20 percent of extensometer locations on ASR-affected structures and will use the approach provided in Appendix C of Report MPR-4273, Revision 1 (Seabrook FP#101050). Seabrook will complete the initial study no later than 2025 and a follow-up study 10 years thereafter. (INT024, encl. 2 at 59–60).

The condition ensures that NextEra continues to gather and analyze expansion data of in-situ structures and ensures that the structures' expansion behavior continues to align with the expansion behavior seen in the LSTP specimens. The implications of any adverse findings from the confirmatory actions in the license condition will be appropriately addressed by NextEra in its Corrective Action Program in accordance with Item XVI, "Corrective Action," of 10 C.F.R. Part 50, Appendix B, and is subject to NRC oversight. Therefore, the Staff determined that the license condition provides additional assurance that the LSTP was representative and/or bounding and that NextEra appropriately used the LSTP data to develop the Seabrook ASR expansion monitoring program.

D. The Monitoring Frequencies Are Acceptable

Q.34. Why are the Seabrook ASR expansion monitoring program's monitoring frequencies acceptable to the Staff?

A.34. Under the LAR, structures with signs of ASR are classified based on expansion to-date and structures with higher levels of expansion are monitored more frequently. Areas with visual indications of ASR are monitored on a 30-month interval and CI/CCI monitoring begins when cracking can be accurately measured. These areas are referred to as "Tier 2." Once in-plane expansion reaches 0.1%, as measured by CI/CCI, the area is classified as "Tier 3" and extensometers are installed, and the inspection interval is shortened to 6 months.

The Staff noted that the inspection frequency increases as ASR degradation progresses, moving from the standard structure deformation monitoring program frequency (generally every 5 years for structures in environments likely to promote ASR) to every 6 months for Tier 3 structures. The Staff reviewed the inspection frequencies and found them acceptable. Five years is an acceptable, conservative monitoring frequency for structures, as indicated in industry guidance documents, such as ACI 349.3R, "Evaluation of Existing Nuclear Safety-Related Concrete Structures" (NRC059). Six months is a conservative inspection interval for structures, regardless of the degradation mechanism, and ASR is a very slow-progressing degradation mechanism. Therefore, inspection frequencies that vary between 5 years and 6 months, depending on identified degradation, provide reasonable assurance to the Staff that any future degradation will be identified and addressed before it could impact a structure's intended function.

E. Staff Conclusion Regarding ASR Expansion Monitoring Program

Q.35. What is the Staff's conclusion based on its review of the Seabrook ASR expansion monitoring program?

A.35. Taken together, the Staff found that NextEra had developed a representative and/or bounding test program and that it is reasonable to apply the conclusions of the LSTP to the structures at Seabrook within the bounds and limits of the test program, regardless of the results of material property testing on ASR-affected concrete cores. This includes using the correlation curve to determine pre-instrument-installation through-thickness expansion and using nominal specified concrete compressive strength and specified minimum yield strength of reinforcement from the original design for concrete strength capacity calculations. The finding also includes using the design strength for anchor bolts and using the Seabrook design codes to calculate concrete flexural strength capacity and shear capacity, provided that through-thickness and volumetric expansion remain below the limits from the LSTP. The finding also imposed a license condition requiring NextEra to implement actions to periodically confirm the continued applicability of the LSTP conclusions to Seabrook structures. Specifically, the license condition requires (1) corroboration of the modulus-expansion correlation developed based on the LSTP and (2) assessments of the Seabrook expansion behavior compared to the test program. For all of these reasons, the Staff concluded that the LSTP and its application to Seabrook were acceptable. This Staff conclusion was found to be appropriate by two additional independent reviews of the LSTP. Specifically, both RES and the ACRS reviewed the relevant information and agreed with the Staff conclusion.

II. The Staff's Response to C-10's Arguments

Q.36. C-10 and its expert, Dr. Saouma, discuss that the NRC contracted for independent research on ASR, including a grant to Dr. Saouma. Is this relevant to the Staff's review of the LAR?

A.36. No. Since NextEra initially identified visual indications typical of ASR, the Staff has taken numerous steps to better understand ASR generically and to make the U.S. nuclear power industry aware of the issue of ASR. In 2011, the Staff issued an Information Notice to all licensees and applicants informing them of the ASR at Seabrook so that they can consider actions, as appropriate, to avoid similar problems at their facilities (NRC060). The Staff has revised the Standard Review Plan for the review of subsequent license renewal applications to describe when applicants may need plant-specific aging management programs to address ASR (NRC061). The Staff has funded independent research projects into ASR, including by the National Institute of Standards and Technology (NIST) (NRC062), the University of Colorado at Boulder (with Dr. Saouma, C-10's expert, as principal investigator) (INT004), and Northwestern University (NRC063). ASR is also being investigated by the Electric Power Research Institute's (EPRI) Long Term Operations research program (NRC064; NRC065), the Department of Energy's (DOE) Light Water Reactor Sustainability research program (NRC066), the Nuclear Energy Agency's (NEA) Committee on the Safety of Nuclear Installations (CSNI), Working Group on Integrity and Ageing of Components and Structures (NRC067; NRC068), and France's Institut de radioprotection et de sûreté nucléaire (IRSN).[17] The NRC plans to use the results of these studies to further its understanding of ASR (NRC070). The Staff also used an expert panel to identify knowledge gap areas with regard to the aging mechanisms of concrete structures for subsequent license renewal to 80 years, which included consideration of ASR (NRC071).

These generic activities, though, are not relevant to the Staff's review of the Seabrook LAR at issue in this proceeding. Consistent with its regulations, when the Staff reviews a license amendment request, it does not determine whether the request could be achieved in some other, arguably better, manner; instead, its decision is guided by the considerations which

[17] *See* NRC069 (discussing the IRSN's "observatory of the durability of reinforced concrete structures" research project).

govern the issuance of initial licenses.[18] These include finding that there is reasonable assurance (not absolute assurance or zero risk, but, rather, a preponderance of the evidence) that the activities authorized by the amendment can be conducted without endangering the health and safety of the public and that such activities will be conducted in compliance with the NRC's regulations.[19] Thus, to the extent that C-10 and Dr. Saouma argue that the LAR could have been better, their argument is irrelevant to this proceeding. To the extent that C-10 and Dr. Saouma argue that the Staff's SE required independent review by outside experts in the field; there is no such requirement. Moreover, the Staff did receive two independent reviews – one by RES and one by the ACRS. Finally, to the extent that C-10 and Dr. Saouma fault the NRC for not having regulatory standards or guidance for ASR, this is also not relevant to this proceeding.

In conclusion, the question at issue in this proceeding is whether NextEra has provided reasonable assurance (i.e., a preponderance of the evidence) that the operation of Seabrook in the manner proposed by the LAR, as conditioned, will continue to meet the relevant NRC requirements; C-10's arguments about different approaches that NextEra could have taken in its LAR are outside the scope of this proceeding.

Q.37. Dr. Saouma cites Federal Highway Administration reports as providing a road map on how to deal with ASR using modern tools (INT001-R at 6). However, he also then criticizes the use of surface measurements of CI/CCI as misleading (INT001-R at 36). Don't these reports endorse the use of CI/CCI?

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[18] 10 C.F.R. § 50.92(a).

[19] 10 C.F.R. § 50.57(a).

A.37. The FHWA Report (NER013) does not place limitations on what CI/CCI can accomplish; however, Appendix B of the report notes that the purpose of the method is to quantify the state of cracking on a concrete member to allow comparative ratings between structural members and to generate data on the evolution of deterioration and establish an appropriate monitoring frequency. Appendix B further notes that structures exhibiting crack widths in excess of those tolerable may be subject to more detailed investigations, including structural analyses. This is almost exactly what NextEra has done with its monitoring programs is and consistent with how it is using CI/CCI at Seabrook. Measurements were taken throughout the LSTP, and on Seabrook structures, and the information was used as an input to develop appropriate monitoring frequencies and limits for additional investigations and analyses.

Dr. Saouma also raises the concern that CI/CCI may underestimate ASR degradation that is occurring inside structural members and that by the time extensometers are installed, it may be "too late" (INT001-R at 21, 33). This could theoretically be a possibility; however, NextEra has been evaluating the core bores taken from Seabrook concrete structures when the CI/CCI limits are reached and extensometers are installed and there has been no indication that degradation inside the concrete members has progressed to a significant level by this time. Additionally, the Staff is not aware of any operating experience where ASR degradation has led to a structural failure of reinforced concrete without visual indications of degradation being present. ASR degradation will manifest itself visually before significantly impacting the capacity of a reinforced concrete member and, therefore, the method of addressing ASR at Seabrook proposed by NextEra of relying, in part, on in-plane cracking measured by CI/CCI is reasonable.

Dr. Saouma also rejects CI/CCI as a monitoring method and suggests other monitoring activities, such as monitoring internal relative humidity (RH) or free chloride concentration, but he does not explain what value these monitoring activities would provide. NextEra knows that there are ASR-affected concrete structures at Seabrook and it is actively monitoring all Seabrook structures for ASR and associated degradation; monitoring RH to determine if ASR will occur serves no practical purpose for ensuring that Seabrook structural members remain safe. Dr. Saouma appears to be focused on how and why ASR is occurring at Seabrook and predicting what will happen in the future, while NextEra has, appropriately, focused on quantifying the structural impacts of ASR and ensuring that Seabrook structures remain safe by remaining within criteria that have been conservatively demonstrated to be safe. Moreover, the Staff notes that the Seabrook structure deformation monitoring program does include periodic sampling and chemical analyses of groundwater at the site for chlorides, sulfates, and pH.

Q.38. C-10 and Dr. Saouma assert that the concrete used in the LSTP was not representative of the concrete at Seabrook. Additionally, Dr. Saouma faults the LSTP because not "all of the sand and aggregates used … were identical to what was used in Seabrook" (INT001-R at 10). What is your response to this?

A.38. As discussed above, the Staff found that the LSTP concrete was representative of Seabrook concrete (see Section I.A., "The LSTP Was Representative and/or Bounding," *supra*).

Contrary to Dr. Saouma's arguments, the point of NextEra's approach was not to simply replicate Seabrook concrete, but to produce ASR expansion (i.e., ASR effects) greater than that currently present in Seabrook concrete so that safe limits could be conservatively estimated for the actual Seabrook concrete. Testing at these higher ASR levels did not indicate reductions in structural capacity and, therefore, as long as the actual Seabrook concrete is below these ASR levels, then it is safe. This is exactly why NextEra chose to create test specimens instead of harvesting specimens.

Additionally, it would have been impossible to recreate Seabrook concrete exactly, as Dr. Saouma advocates. All concrete mixes are going to have inherent differences based on the aggregate and sand used and the type of cement, etc. Even if the aggregate and sand were taken from the same source, there would be differences in the final product. However, this does not mean that concrete cannot be specified to meet particular criteria, such as water-cement ratio or compressive strength, and that the resulting concrete is not similar enough for comparison. To build on Dr. Saouma's example of bread, no two loaves of bread are ever exactly the same; however, recipes can be followed to develop a particular type of bread (e.g., baguette, ciabatta, etc.). Concrete is similar in that no two concrete samples will ever be exactly the same due to differences in the constituents (e.g., aggregate, sand, cement, etc.); however, specifications, or "recipes," can be provided that, if followed, will create concrete that is similar enough that it can be treated as the same for design purposes. The LSTP used the original Seabrook recipe and ensured that each ingredient matched the original Seabrook recipe ingredient as closely as reasonably possible in developing its test specimens. Accordingly, Dr. Saouma's criticism that the concrete in the LSTP is not identical to the concrete at Seabrook is not relevant to the Staff's safety determination.

Similarly, Dr. Saouma states that, "we have no idea of the potential ultimate expansion at Seabrook" (INT001-R at 11), but such knowledge is not necessary – what is relevant is that the expansion at Seabrook is monitored and remains within the representative and/or bounding expansion limits of the LSTP, and that NextEra continues to monitor the Seabrook structures to ensure that they remain within these limits.

Finally, to the extent that there are any substantive differences between the LSTP concrete and Seabrook concrete, the Staff found that the license condition imposed as a requirement for the issuance of the amendment provides additional assurance that these differences will not affect the public health and safety. NextEra is required to address any inconsistencies that may be identified in the future and this would also be subject to NRC oversight.

For these reasons, the LSTP approach taken by NextEra is one acceptable way to provide reasonable assurance (not absolute assurance or zero risk, but, rather, a preponderance of the evidence) of adequate protection of the public health and safety.

Q.39. Dr. Saouma claims in Section C.2.2 of his testimony that NextEra and its consultants made multiple errors with respect to the design of the LSTP such as with respect to specimen dimensions, boundary conditions, and loads (INT001-R at 11). What is your response to this?

A.39. Dr. Saouma claims that the LSTP's failure to scale the test specimens to the dimensions of Seabrook using principles of scaling for model testing prevents it from being representative with regard to introducing the potential for an erroneous failure mechanism. This argument is not relevant because the tests conducted in the LSTP use almost full-scale test specimens representative of a bounding reference location of a typical wall segment in a Seabrook ASR-affected seismic category 1 structure (e.g., the "B" electrical tunnel). The length and width of the test specimens are the actual dimensions at the reference location and the height is that of a representative segment (or slice) of that location (which had to be limited due to the space and equipment restrictions of load testing in a laboratory). The test specimens included two-dimensional reinforcement mats using the same reinforcement size and spacing, one along each longitudinal face, and with no shear reinforcement as in a typical wall at Seabrook. The test specimens dimensions are significantly larger than the existing literature data and as close to the full-scale of Seabrook structures as is practical. The tests conducted were thus full-scale load tests to failure and not model tests; therefore, there was no scaling involved and Dr. Saouma's argument regarding scaling is not relevant.

To summarize the LSTP philosophy, the test programs were designed to maximize representativeness of actual reinforced concrete structures at Seabrook using a reasonable number of test specimens. The specimens were designed to be representative of a bounding reference location at the plant. To enable the application of the results to other structures, the test results are compared to control specimens and to provisions in ACI 318-71 to determine if an appropriate reduction factor was necessary. This approach is appropriate because the LSTP's methodology is consistent with the experimental methods used to generate the data on which the code equations in ACI 318-71 are based. Seabrook includes many reinforced concrete structures and the specific configuration of structural components within those structures may vary. Because the approach of the LSTP supplements (rather than replaces) the design code, results from appropriately representative test specimens may be applied to reinforced concrete structures throughout Seabrook. Additionally, the test specimens' design includes specific features that represent actual structures at Seabrook to the maximum extent practical. Therefore, the Staff concluded that this approach satisfies the relevant standard of providing reasonable assurance of adequate protection of the public health and safety.

Q.40. Dr. Saouma claims in Section C.2.2.2 of his testimony that the LSTP test specimens (which he considers to be models) were not subjected to the same conditions (support, restraints, and load) as at Seabrook (which he considers to be the prototype) and, therefore, the LSTP cannot be seen as a representative model of Seabrook (INT001-R at 12–13). What is your response to this?

A.40. Contrary to the assumption that is central to this assertion, the LSTP was not a model test; rather, as discussed in the answer to the previous question, it was a full-scale load test, consistent with the test methodology on which the ACI 318-71 empirical code equations for structural capacity (for strength limit states such as flexure and shear) were developed, created to determine the impact of ASR on structural capacity for specific limit states. The individual tests were designed to ensure that the failure mode of each test specimen supports the limit state of interest in that test. The purpose of the tests was not to validate or calibrate a numerical simulation model for ASR (as Dr. Saouma seems to advocate be done), but to validate the applicability and/or limitations of the ACI 318-71 (NRC049) code equations for estimating structural capacity for critical limit states for ASR-affected reinforced concrete structures at Seabrook. The issues that Dr. Saouma raises in this part of his testimony might be valid if the purpose of the LSTP was to validate a numerical simulation model for ASR; however, this was not the purpose of the LSTP and, therefore, the issues are not relevant to the LSTP. Nevertheless, the Staff notes that the finite element models used in the Seabrook structure deformation monitoring program to conduct the structure-specific analysis to determine the structural demand under design basis loads, including ASR, do include boundary conditions (support, restraints, and load) of the actual structure being analyzed. The effects and combination of ASR prestressing effect, axial forces caused by weight, in-plane and out-of-plane shear, etc., are incorporated in these analyses. However, again, that was not the purpose of the separate LSTP; the purpose of the LSTP was to determine the impact of ASR expansion on structural capacity as it relates to the use of ACI 318-71 (NRC049) code equations and provisions for ASR-affected structures at Seabrook.

To respond to Dr. Saouma's comment on in-plane and out-of-plane shear, the LSTP did not test for the in-plane shear mode. This was because the out-of-plane shear failure mode was judged to be more critical than in-plane shear mode (note: nominal permissible out-of-plane shear stress in concrete per the ACI 318-71 code is $2*\sqrt{f'_c}$ versus allowable total shear stress of

10*$\sqrt{f'_c}$ for in-plane shear (NRC049 § 11.4.1 at 37, § 11.16.5 at 42); here f'_c is the specified minimum concrete compressive strength). Additional discussion with regard to in-plane shear capacity of ASR-affected walls is provided in Section 1.A.vii., "The Treatment of Seismic Response Was Representative and/or Bounding," *supra*. To respond to the comment regarding axial forces due to dead weight, these axial forces are compressive and have a beneficial effect on structural capacity in flexure and shear for in-situ structures such as those at Seabrook.

Q.41. Dr. Saouma claims in Section C.2.3.1 of his testimony, with regard to the LSTP's Shear Test Program, that the load-displacement curve in MPR-4273, Rev. 1, Figure 5-5 (proprietary) (INT021 at 5-7) is not indicative of a shear failure with minimum (or no reinforcement) and that clearly some shear reinforcement is present (INT001-R at 13–14). Specifically, pointing to his Figure 5, Dr. Saouma argues that what likely happened was a crack in the zone of the beam with the shear reinforcement (INT001-R at 14). What is your response to this?

A.41. The shear tests conducted in the LSTP were 3-point load tests. Unlike what is shown in Figure 5 of Dr. Saouma's testimony (INT001-R at 14), in the LSTP, the left support of the beam was located to the right of the end area with stirrups and, therefore, the test span did not include any shear stirrups. ACI 318-71 determines shear capacity (strength) based on the onset of diagonal (tension) or inclined cracking (NRC049 §§ 11.4.1, 11.4.2, 11.2.3, 11.2.4). Diagonal cracking occurred in the ASR-affected specimens at the load level indicated by the "blip," as Dr. Saouma called it (INT001-R at 14), in Figure 5-5 of MPR-4273, Rev. 1 (INT021 at 5-7) (proprietary). The physical appearance of the specimens at the "blip" load level showed clear evidence of diagonal cracking within the test spans. The diagonal cracking typically developed in the lower half of the test specimens, extending from the mid-plane ASR crack down toward the support (NER022). Continuous loading of the specimen after first diagonal cracking generally resulted in extension of the initial diagonal crack toward the load point in the top half of the specimens (NER022). Failure of the specimens was indicated by significant distress in the form of concrete crushing at the location of the hydraulic ram (load point), which occurred at a higher load level (NER022). The shear capacity was, however, determined to be the load level at the onset of the diagonal crack (shear failure by diagonal tension which results from a combination of flexural tension stress and shear stress).

Section 7.3 of the textbook "Reinforced Concrete Structures," by R. Park and T. Paulay discusses two types of behavior that have been observed in tests related to the formation of diagonal cracks and shear resistance mechanisms in reinforced concrete beams without shear reinforcement (NRC072 at 256). It states, "[e]ither a reinforced concrete flexural member collapses immediately after the formation of diagonal cracks, or an entirely new shear carrying mechanism develops which is capable of sustaining further load in a cracked beam" (NRC072 at 256). The behavior of the LSTP's Shear Test Program specimens fall into the latter category, but are still valid shear tests consistent with observed behavior of diagonally cracked beams reported in the literature. Similar observations of the behavior of diagonally cracked beams without shear reinforcement, with failure load possibly significantly higher than that at which the diagonal crack first formed, are also explained in Section 5.3.b of the textbook "Design of Concrete Structures," by David Darwin, et. al. (NRC073 at 138–141).[20]

Based on the above information, Dr. Saouma's argument regarding load displacement is not valid.

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[20] In their disclosures, C-10 disclosed the following: "D. Darwin, C. Dolan, and A.H. Nilson (2014). *Design of Concrete Structures*. 15th Ed. McGraw-Hill." The date of the 15th Ed., however, is 2016, and the link C-10 provided was to the 14th Ed. (2010). The section cited above on Reinforced Concrete Beams without Shear Reinforcement (§ 4.3 in the 14th Ed. and § 5.3 in the 15th Ed.) is, other than the section number, identical in both editions. The 15th Edition is NRC073.

Q.42. Dr. Saouma claims in Section C.2.3.2 of his testimony that the unanticipated crack shown in MPR-4273, Rev. 1, Figure 4-2 (INT021 at 4-4 (proprietary)) should be of the utmost concern as it jeopardizes the representativeness of the ensuing test and would cause the results to be unreliable (INT001-R at 15–16). What is your response to this?

A.42. As ASR progressed in the LSTP beam test specimen, a relatively large crack was observed near the center of the surfaces of the specimen between the reinforcement mats as depicted in Figure 4-2 of MPR-4273 (INT021 at 4-4 (proprietary)). This crack was determined by NextEra/FSEL to be an “edge effect” where expansion was concentrated into a large crack due to a lack of confinement (INT021 at 4-4–4-5 (proprietary)). By sectioning the beam cross-section (i.e., cut with a wire saw) of a sample of the test specimens after load testing, NextEra/FSEL confirmed that the large crack observed on the surfaces between the reinforcement mats was indeed an edge effect that penetrated only a few inches into the specimen and did not compromise the representativeness of the test region. The sectioning also confirmed that the large crack on the peripheral surfaces was not a delamination of the section as claimed by Dr. Saouma. By examining the sectioned cross-section, NextEra/FSEL also observed that along the specimen edges, expansion is concentrated in the large crack; whereas, away from the edges, expansion is of about the same magnitude but distributed into finer cracks across the specimen cross sections. A crack like this is not expected to occur in Seabrook structures due to confinement effects provided by adjoining structural members that were cast integrally. The sectioning of the test specimens provided reasonable assurance that the large crack was an edge effect that did not compromise the representativeness of the test specimens and the conduct of the test. Therefore, the test remains representative and/or bounding and the results of the tests remain valid.

Q.43. Dr. Saouma claims in Section C.2.4.1 of his testimony that NextEra confuses material strength with structural strength (INT001-R at 17). What is your response to this?

A.43. Dr. Saouma is referring to the material properties of concrete (e.g., compressive strength, tensile strength, etc.). When affected by ASR, the material properties of concrete are degraded. This is well known in existing ASR literature and the results of the LSTP showed the expected reductions in material properties. NextEra acknowledged these results; however, the entire point of the LSTP was to demonstrate that although concrete material properties may be reduced, the structural performance of the reinforced concrete member can still be conservatively estimated by the design basis code equations. Thus, NextEra is not confusing material strength with structural strength, it is relying on the LSTP results to demonstrate that structural strength is unaffected as long as the expansion remains below the identified limits from the LSTP, regardless of the reductions in material strength. This point that Dr. Saouma highlights is exactly why NextEra performed the LSTP, i.e., to more clearly identify the impact of ASR on reinforced concrete in the structural context and not just in the material context.

Q.44. Dr. Saouma claims in Section C.2.4.2 of his testimony that assuming that ASR can be considered a load is "fundamentally wrong" and that structural engineering involves ensuring that capacity exceeds demand where demand is the result of load and capacity is the ability of the structure to resist load by virtue of its strength (INT-001-R at 17–18). What is your response to this?

A.44. The Staff agrees that the demands on a structure are the loads applied to the structure, while the capacity of the structure is its ability to resist the loads. Although ASR reduces material properties of unreinforced concrete, the LSTP results showed that ASR does <u>not</u> reduce the capacity of reinforced concrete structural members within the ASR levels tested. Because of the LSTP results, NextEra continued to use the code equations when estimating capacity, with no reductions for ASR. Although ASR does not reduce capacity, within the ASR levels tested, restraint to its expansion does apply a self-equilibrating internal tensile force to the reinforcement and an internal compressive force to the concrete, which produces additional demand that must be resisted by the structure. NextEra acknowledged this load and chose to address it by adding it to the design basis load combinations as a self-straining load in structural analyses performed in support of the Seabrook structure deformation monitoring program. An analogy could be made with regards to thermal expansion that is accounted for in normal concrete design and construction. Temperature reinforcement is used for temperature stresses caused by normal environmental factors and the concrete curing process and resists and controls the effects of thermal expansion. ASR expansion could be considered similarly, except that normal concrete design assumes ASR will not occur in the structure and, therefore, no associated load will occur. In Seabrook's case, ASR has occurred and NextEra has acknowledged that there is an applied load that must be accounted for in the demand on the structure. If NextEra did not account for this load, then that would be a "fundamental flaw" in its approach.

Q.45. Dr. Saouma claims in Section C.3.1.1 of his testimony that page 55 of the SE (INT024) makes several statements that are not supportable in that FSEL measurements cannot be applied at Seabrook, there is no basis for what constitutes conservative limits measured in the LSTP, and ASR is not monitored as it progresses (INT001-R at 18–19). What is your response to this?

A.45. Although Dr. Saouma faults the LSTP for not providing a "direct connection" with Seabrook (INT001-R at 19), the point of the LSTP was to, rather, provide limits that are representative and/or bounding of the ASR at Seabrook. The LSTP test specimens were designed to be representative of a typical wall segment affected by ASR at Seabrook. The representativeness was achieved in terms of concrete aggregate gradation, water-to-cement ratio, specified compressive strength at 28 days, specimen length and thickness, rebar size, and reinforcement mat configuration such that expansion effects for a given level of ASR would be expected to be similar between the test specimens and Seabrook structures. Of course, the concrete ingredients for the test specimens were modified to accelerate ASR and to achieve, in a reasonable timeframe, expansion levels well beyond those experienced by Seabrook structures. This is a typical approach used, to the Staff's knowledge, in all ASR research programs, both nationally and internationally, except for exposure sites (locations where 'normal' concrete with ASR is allowed to age and react naturally over extended timeframes), and does not have any known significant impact on the representativeness of the results.

The primary goal of the LSTP was to achieve ASR effects (e.g., expansion, cracking, etc.) in the test specimens that are representative and/or bounding of the effects on actual Seabrook structures. The test specimens were tested to failure at various levels of ASR progression to determine ASR's impact on structural capacity performance for the critical limit states. ASR expansion was characterized on the test specimens in terms of in-plane expansion in two directions (using CI/CCI and pin-to-pin measurements) and through-thickness expansion (using pin-to-pin and Z-frame, as well as using SRBE, measurements). The volumetric expansion was calculated as the sum of the expansions in the three directions. The maximum expansion levels, without impact on structural capacity, achieved in the Reinforcement Anchorage Test Program and the Shear Test Program were slightly different and, therefore, the lower of the two maximum expansion limits was chosen as conservative expansion limits (through-thickness and volumetric) in the ASR expansion monitoring program for Seabrook structures. Taken together, structural capacity determined using code equations remains valid as long as ASR expansion (through-thickness and volumetric) measured at Seabrook remains within the bounds of the LSTP-derived limits.

Separately, the effect of ASR on structural demand and deformation in combination with other design basis loads is addressed in the structure deformation monitoring program. The three-stage structure-specific evaluation (which may include finite element analysis) conducted as part of the structure deformation program determines threshold monitoring parameters and maximum (upper bound) threshold limits within which code acceptance criteria are met. These structure-specific threshold parameters are monitored against threshold limits. If they remain within the threshold limits, it means that structural demand under design basis loads, including ASR effects, does not exceed design capacity.

If any of the monitoring limits are approached or exceeded, in either the ASR expansion monitoring program or the structure deformation monitoring program, its implications will be addressed in NextEra's corrective action program and is subject to NRC oversight. Moreover, the results of the LSTP will be confirmed by the license condition required as part of the Staff's approval of the LAR. Therefore, despite Dr. Saouma's statements to the contrary, the progression of ASR effects on Seabrook structures is monitored periodically against specific limits as ASR progresses. This approach does not rely on predictions with regard to expansion rate or ultimate expansion, but, rather, to representative and/or bounding limits from the LSTP.

Because of the design of the LSTP and NextEra's approach to addressing ASR at Seabrook, as summarized above, the concerns raised by Dr. Saouma do not affect the Staff's determination that there is reasonable assurance of adequate protection of the public health and safety.

Q.46. Dr. Saouma claims in Section C.3.1.2 of his testimony that, as a monitoring measure at Seabrook, CCI must be ruled out completely (INT001-R at 21). What is your response to this?

A.46. CI/CCI is a commonly used method to provide an estimate of in-situ expansion of ASR-affected structures. The method has been recognized in the FHWA Report (NER013).

Dr. Saouma argues in his testimony, by reference to Figure 1 in the FHWA Report (NER013 at 5),[21] that Section 2.2 of this report indicates that CI/CCI can only be used in conjunction with petrography. Dr. Saouma, however, fails to recognize that Section 2.2 of the FHWA Report is entitled, "ASR Investigation Program Level 2: Preliminary Studies for the Diagnosis of ASR," and that the portion of its Figure 1 to which he refers is also marked as "Level 2 Preliminary Investigation Program" (NER013 at 3, 5). Therefore, the context of the FHWA Report's recommendation to use petrography in addition to CI/CCI in fact relates to only the early detection and diagnosis of ASR in concrete. This guidance, though, is not relevant to Seabrook because ASR has already been diagnosed and confirmed at Seabrook based on the petrographic examination of cores, and because the same reactive coarse aggregate was used in the concrete mix for all concrete structures at Seabrook, NextEra considers any future visual indications of concrete degradation at Seabrook to be due to ASR.

Moreover, the FHWA Report <u>does</u> recognize CI/CCI as an in-situ method that gives a quantitative assessment of the extent of cracking in structural members, which is related to the overall amount of expansion reached in the affected concrete member. The FHWA Report notes that CI/CCI provides a quantitative rating of the surface deterioration affecting the structure as a whole (NER013 at 23). The FHWA Report includes CI/CCI and monitoring of

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[21] Although Dr. Saouma refers to this Figure as "Figure 12," the cited figure is Figure 1 in the FHWA Report (NER013 at 5).

deformations/movements as recommended in-situ methods that can be used for estimating the expansion attained to date in ASR-affected concrete members (NER013 at 23, 31). This is exactly what was done by NextEra – at Seabrook, CI/CCI is used to estimate the expansion-to-date in the in-plane direction of ASR-affected structures. Additionally, NextEra installed permanent pins to mark the boundaries of the CI grids and serve as DEMEC mechanical strain gauge points for more accurate future expansion measurements. Therefore, the use at Seabrook of CI/CCI or baseline CI/CCI in combination with subsequent pin-to-pin measurements to characterize and monitor the progression of in-plane ASR expansion is consistent with industry practice.

Cracking is always more pronounced on the free surface of a structure because that is where it is most free to develop and grow. The use of CI/CCI to estimate in-plane expansion-to-date on structures is considered conservative because, although surface cracking can also be influenced by other mechanisms such as temperature variation, drying and wetting cycles, and shrinkage, all the cracking (except for obvious structural cracks) are attributed to ASR. Unless in-situ expansion monitoring was done from the time of construction (e.g., insertion of pins during construction), the Staff is not aware of a practical method other than CI/CCI to estimate in-plane expansion-to-date when ASR is diagnosed many years after original construction. Once the baseline in-plane expansion-to-date is obtained using CI/CCI, pin-to-pin expansion measurements on the CI grid using DEMEC mechanical strain gauges provide a more accurate method of monitoring the progression of in-plane expansion. This approach is also being used at Seabrook.

In support of his argument that CI/CCI must be ruled out completely, Dr. Saouma also states that (1) in New Hampshire, temperature is much lower on the surface of the wall and there is a thermal gradient with the much warmer concrete inside and (2) the inside of the concrete would maintain higher humidity due to the surface of the walls having dried due to shrinkage a long time ago (INT-001-R at 20–21). Dr. Saouma further asserts that, therefore, should cracking be noticeable through CI/CCI, that would imply that the internal swelling was so great that it affected surface cracking and that it may be “too late” by the time extensometers are installed (INT-001-R at 21).

This argument against the validity of CI/CCI is incorrect. Internal ASR expansion that has no visual manifestations on the surface is not significant with regard to structural performance. Expansion of any significance will manifest on the surface in the form of cracking, spalling, pop-outs, relative displacements, or deformation long before any structural intended functions are impacted. Moreover, field evidence from cores that were removed at Seabrook in support of the installation of extensometers at both above and below grade locations has not shown any indications of structural concern in the concrete interior. Therefore, the use of CI/CCI provides reasonable assurance of adequate protection of the public health and safety (see also Section 1.A.ix., “The Measurement of In-Plane Expansion is Consistent with Industry Practice,” *supra*).

Finally, Dr. Saouma argues that additional petrographic studies should be conducted to characterize the out-of-plane or through-thickness expansion that occurs in a plane parallel to the surface and is not reflected in the CI/CCI (INT001-R at 20, 31). Dr. Saouma suggests that the Damage Rating Index (DRI) method should be used (INT001-R at 20, 32). The FHWA Report notes that, while the DRI method may be useful for quantitative assessment of internal damage in concrete, there is no standard procedure (NER013 at 96). The method is fairly subjective and the results can be quite variable from one petrographer to another (NER013 at 96). Dr. Saouma hints at this in his testimony when he “caution[s] that [DRI] is a delicate test that should only be performed by a very qualified petrographer, and should be performed repeatedly by the same one" (INT001-R at 31). Instead of relying on a delicate test and only one dedicated petrographer, NextEra employs an SRBE installed to a depth almost through the entire thickness of the concrete member (i.e., within a few inches of the far surface) to monitor through-thickness expansion progression. The Staff's review of the LAR evaluated the acceptability of the monitoring methods NextEra proposed, and the DRI method was not chosen for the reasons stated above. The Staff's review of the SRBE method of measuring through-thickness expansion found that this approach is effective. Therefore, Dr. Saouma's argument regarding the DRI method does not demonstrate that the LAR is not protective of the public health and safety.

For all of the foregoing reasons, Dr. Saouma's argument regarding the validity of CI/CCI fails.

Q.47. Dr. Saouma makes arguments regarding the structure deformation monitoring program in Sections C.3.3 and C.3.4 of his testimony (INT001-R at 22–24). What is your response to this?

A.47. This proceeding has to do with the representativeness of the LSTP. As discussed in Section V, "The Structure Deformation Monitoring Is Outside the Scope of this Proceeding," *supra*, the process used in the structure deformation monitoring program, including the performance of finite element analyses, does not rely on the LSTP and is, therefore, outside the scope of this proceeding. Since the process used in the structure deformation monitoring program is outside the scope of this proceeding, the Board should not address the issues that Dr. Saouma raises with respect to this process.

Dr. Saouma attempts to get around this limitation on the scope of the instant proceeding by pointing out that the ASR expansion monitoring program refers to the structure deformation monitoring program. Specifically, Dr. Saouma points out that Table 5 of the LAR provides that the recommended actions for Tier 3 structures, those with in-plane expansion of 0.1%, are a "[s]tructural evaluation" and enhanced ASR monitoring (INT010 at PDF 33). This, though, does not, as Dr. Saouma claims, make the process used in the structure deformation monitoring program "an integral part of ASR expansion monitoring" (INT001-R at 24); rather, it is a simple pointer for the Seabrook staff to initiate a process (or evaluation) separate from the ASR expansion monitoring program's process. Stated another way, when in-plane expansion reaches 0.1%, the ASR expansion monitoring program triggers two follow-on actions – (1) implementing enhanced ASR monitoring under the ASR expansion monitoring program (i.e., installing an SRBE to measure through-thickness expansion) and (2) initiating structural evaluation under the structure deformation monitoring program. This "[s]tructural evaluation" follows the separate process described in Sections 3.3 and 3.5.2 of the LAR and summarized in the separate Table 6 of the LAR (INT010 at PDF 34). Thus, the "[s]tructural assessment" under the structure deformation monitoring program is only triggered by, but not a part of, the ASR expansion monitoring program.

Dr. Saouma also tries to conflate the two programs by noting that Section 3.5.2 of the LAR is titled "Structure Deformation" and not "[S]tructure [D]eformation Monitoring" (INT001-R at 23), but this does not somehow mean that Section 3.5.2 is a part of the ASR expansion monitoring program. On the contrary, a plain language reading of the LAR indicates that Section 3.5.2 has to do with only the structure deformation monitoring program and not the ASR expansion monitoring program because Section 3.5 is titled "Monitoring" and it is broken up into Section 3.5.1, "ASR Expansion [Monitoring]," and Section 3.5.2, "Structure Deformation [Monitoring]" (INT010 at PDF 30, 31, 33).

In conclusion, Dr. Saouma has no support for his conflation of the structure deformation and ASR expansion monitoring programs. Moreover, even if he did, the scope of this proceeding is limited to the representativeness of the LSTP, and the simple assertion that the structure deformation monitoring program is a part of the ASR expansion monitoring program does not show that the process used in the structure deformation monitoring program relies on the LSTP. On the contrary, as discussed in Section V, *supra*, the aspects of the structure deformation monitoring program that Dr. Saouma challenges (e.g., finite element analysis) do not rely on the LSTP. Therefore, the Board should not address the issues that Dr. Saouma raises with respect to the structure deformation monitoring program.

Q.48. In Section C.3.4.1 of his testimony, Dr. Saouma lists "concerns" based on Simpson, Gumpertz, & Heger, Inc., "Evaluation and Design Confirmation of As-Deformed CEB, 150252-CA-02," Revision 0, July 2016 (INT015) (INT001-R at 24–28). How do you respond to these concerns?

A.48. As an initial matter, Dr. Saouma's concerns with this report are not relevant to this proceeding because the referenced calculation was originally submitted as an implementation example of the licensee's analysis method. This method was revised during review of the LAR, and the updated method was captured in a "methodology document," which was submitted on the docket and reviewed by the Staff as part of the LAR review (NRC015). The referenced calculation was revised to match the submitted methodology document, and the revised version (Revision 2) was reviewed by the Staff during a site visit the week of March 19, 2018 (NRC044, encl. at 3; INT024, encl. 2 at 56). Additionally, the finite element analysis approaches the licensee chooses to use to analyze it's structures are not impacted by the fact that the structures are affected by ASR and are in no way impacted by the LSTP; therefore, they are outside the scope of this proceeding. However, the Staff will attempt to address some of the concerns raised by Dr. Saouma in Section C.3.4.1 of his testimony (INT001-R at 24–28), as follows.

Dr. Saouma asserts that ASR and its impact at Seabrook cannot be analyzed using linear elastic methods (INT001-R at 24–26, 36). This argument is not persuasive.

In the Seabrook licensing design basis, reinforced concrete structures were designed so that the behavior of the structure is in the small deformation elastic range under design basis loads and load combinations. Specifically, for containment, the structural acceptance criteria in the Seabrook UFSAR, Section 3.8.1.5, state that "[t]he containment structure, including liner and penetrations, was designed to remain within elastic limits under service load conditions and under the mechanical loads of the factored load conditions…. The design limits imposed on the various parameters that serve to quantify the structural behavior and provide a margin of safety are in compliance with Article CC-3000 of [the ASME Code, Section III,] Division 2" (NRC007 § 3.8.1.5). The ASME Code, Section III, Division 2 uses the working stress design philosophy (NRC050 at 183–216). For containment internal structures and other seismic Category 1 structures, the structural acceptance criteria in the Seabrook UFSAR, Sections 3.8.3.5 and 3.8.4.5 state that they were proportioned to maintain elastic behavior under all normal and unusual load conditions (NRC007 §§ 3.8.3.4, § 3.8.3.5, § 3.8.4.4, § 3.8.4.5). The upper bound of elastic behavior was taken as the yield strength capacity of the load carrying components. Reinforced concrete structures (other than containment) were designed in accordance with the ACI 318-71 strength design method (NRC049 at §§ 8.1.1, 8.1.3).

The approach proposed by NextEra for analyzing ASR-affected structures at Seabrook maintains the same criteria that the behavior of the structures and structural components (as a reinforced concrete system) will remain within the upper bound of elastic behavior under all design load combinations, including the ASR load. The results of the LSTP provided additional technical basis in support of this. Specifically, the load-deformation plots of the representative ASR-affected large-scale structural beam specimens tested to failure generally showed linear behavior up to the point of flexural yielding (in the Reinforcement Anchorage Test Program) or initiation of the diagonal crack (in the Shear Test Program) similar to the behavior of the control specimens and the assumptions in the code (INT020 fig. 5-5 at 5-7, fig. 5-7 at 5-11 (proprietary)). Based on this information, it was reasonable to use linear elastic methods to analyze ASR-affected structures at Seabrook.

It is also reasonable to use the original design methods to evaluate existing structures as long as the original design assumptions are maintained and the effects of any observed degradation of significance (e.g., ASR effects) are reasonably accounted for and it is ensured that capacity is greater than or equal to load effects (including ASR). The LSTP results indicate that the behavior of ASR-affected structures may be considered to be bounded by original design methods, that is, the code equations provide a lower bound estimate of structural capacity of ASR-affected concrete members. Such a conclusion has been made previously by other researchers based on large-scale testing. For instance, “Flexural Strength of Beams Affected by ASR,” by Stephane Multon, et.al., concluded that flexural tests showed that “[c]lassical methods of calculations of reinforced concrete structures may be used for structures damaged by ASR” (NRC074 § 6). Additionally, Technical Report 12-8XXIA006, summarizing work conducted for the Texas Department of Transportation at FSEL, by Dean J. Deschenes, et. al., concluded that the shear strength of sectional and deep beam shear spans “was not compromised by transverse concrete expansions of 0.69 and 0.45 percent, respectively” (NRC075 at 226). It further concluded that the shear capacity of sectional and deep beam shear spans “may be conservatively estimated using current code provisions in combination with core-based or cylinder-based material strengths” (NRC075 at 226).

Dr. Saouma also states as a concern that “no serious researcher would rely on [CI as an indicator of ASR]” (INT001-R at 26). However, as discussed above, the LAR does not rely on

CI/CCI as an indicator of ASR; rather, it assumes that concrete degradation is due to ASR (see A.46, *supra*). Moreover, the use of CI/CCI to measure ASR expansion is acceptable because it provides a practical and conservative approach to estimate in-plane expansion on real structures, it is among the methods commonly used in practice, and it is recommended in the FHWA Report.

Dr. Saouma states again that NextEra is confusing capacity with demand and questions its assumption that concrete material properties are not reduced due to ASR. These issues are repetitions of his previous comments related to the LSTP and have already been addressed. The Staff, and NextEra, acknowledges that ASR degrades concrete properties when measured via testing of core bores; however, the results of the LSTP demonstrate that there is no impact on in-situ structural capacity of reinforced concrete components within the expansion levels identified in the testing.

In item 7, on page 25 of his testimony (INT001-R), Dr. Saouma quotes the SG&H containment enclosure building calculation and claims that there is an error in the calculation because the calculation states that the same aggregate source was used for the concrete fill and the containment enclosure building but MPR-4273 states that only a portion of the aggregate came from the original quarry. Dr. Saouma is correct in his statement regarding the MPR-4273 document; however, he misunderstood the statement in the SG&H calculation. The statement in the calculation is referring to the aggregate in the concrete backfill used at Seabrook during original construction, which was the same as the aggregate used in the containment enclosure building. Therefore, NextEra conservatively assumes that all concrete backfill onsite may experience ASR.

Based on this information, the Staff concludes that ASR and its impact at Seabrook can be analyzed using linear elastic and code-based methods.

Q.49. Dr. Saouma claims in Section C.3.4.1.1 of his testimony that a "Probabilistic Based Analysis" should have been performed (INT001-R at 29). What is your response to this?

A.49. As stated previously, it is not relevant to the Staff review that the proposed approach could have been done differently (see Section I.A., "The LSTP Was Representative and/or Bounding," *supra*). The Staff found that the methodology and supporting bases proposed by NextEra in the LAR is one acceptable approach for evaluating structures affected by ASR to meet regulatory requirements and provided reasonable assurance that the ASR-affected structures remain capable of performing their intended safety functions. Therefore, Dr. Saouma's argument that a better approach is available is not within the scope of this proceeding.

Q.50. In multiple locations in his testimony, Dr. Saouma raises concerns about NextEra's inability to predict the maximum expansion of Seabrook concrete (INT001-R at 10–11, 26, 31). What is your response to this?

A.50. Dr. Saouma correctly notes that NextEra did not run tests to try to estimate the remaining ASR expansion or to predict when ASR would stop occurring; however, Dr. Saouma does not explain why this is a safety concern. NextEra has chosen a different engineering evaluation approach to ensuring the safety of Seabrook structures that does not involve predictions of ASR kinetics and ultimate expansion. NextEra has identified reasonable and justifiable structure-specific expansion limits, which account for potential future expansion by setting the maximum level of expansion at which the code acceptance criteria are met, and is actively monitoring all safety-related structures to ensure that they remain within these limits. If a limit is approached or reached, its implications will be addressed in the Seabrook corrective action program and will be subject to NRC oversight. Knowing the ultimate expansion is not relevant to the approach chosen by NextEra because the ultimate expansion is irrelevant as long as the structures are monitored and remain below the limits. Knowing the rate of expansion could be helpful if NextEra were going to identify unique inspection frequencies for each structure based on the rate of reaction; however, NextEra has chosen to identify conservative frequencies for all structures, which will identify ASR degradation in a timely fashion regardless of its rate of reaction.

Q.51. In multiple locations in his testimony, Dr. Saouma uses phrases such as "potentially dangerous," "very dangerous," "grave mistake," "fatally compromise," and "it may be too late," to describe the risk significance of ASR and its potential implications on Seabrook (INT001-R at 5, 6, 11, 18, 27, 33). Is this a fair characterization of the risk significance of ASR at Seabrook?

A.51. Since the discovery of ASR at Seabrook, the Staff has held various seminars, workshops, and conferences with ASR material and structural experts. The Staff has also consulted literature, including operating experience, on ASR and its structural significance authored by experts. The following are some expert opinions that informed the Staff's understanding of ASR and the risk significance of ASR at Seabrook.

Canadian Standards Association (CSA) A864-00, "Guide to the Evaluation and Management of Concrete Structures Affected by Alkali-Aggregate Reaction," notes that the risk of sudden structural failure in concrete components affected by AAR is almost non-existent (NRC076 at 13). In the book by Geoffrey E. Blight and Mark G. Alexander, "Alkali-Aggregate Reaction and Structural Damage to Concrete – Engineering Assessment, Repair and Management," the Epilogue, "A check-list of important structural consequences of AAR," states, "AAR is a durability problem that is unlikely to cause structural failure" (NRC077 at 227). In that same section, the authors go on to state that "[t]here are no cases on record where AAR has been the primary cause of structural collapse" (NRC077 at 227). They further state that, "In-situ concrete properties can usually be expected to be considerably better than properties measured on cores in a laboratory" (NRC077 at 228). They also state that "AAR-damaged structures can reach and exceed their design service life with minimal repair and preventive maintenance" and note that this has been proven by many examples and case histories cited in chapters 4 and 5 of the book. (NRC077 at 229).

Q.52. C-10 states that peer review is "a cornerstone of engineering practice" and that peer reviewers must (1) be sufficiently detached from the project organization (i.e., not ultimately report to the same hierarchy), (2) be familiar with the literature, and (3) have a degree of scientific expertise and rigor that is sufficient to enable them to credibly comment (INT001-R at 35). C-10 then faults the NRC for not having such peer reviews (INT001-R at 35). Separately, C-10 faults NextEra and its contractors for having "no in-house expertise on ASR…." (INT001-P at 36). What is your response to this?

A.52. C-10's argument that the NRC must perform peer reviews and that NextEra must have an in-house ASR expert is not persuasive for the simple reason that there are no such requirements with respect to license amendment requests. Moreover, C-10 does not demonstrate why these things would be necessary for the Staff to reach the finding that is, in fact, required, which is that NextEra has provided reasonable assurance that, with the license amendment, as conditioned, Seabrook will continue to meet NRC requirements. Instead, as explained above, based on all of the information that it had gathered regarding ASR at Seabrook since 2009, including through NextEra's submission of the LAR and its license renewal application, and the many supplements to these filings, and through inspections, audits, RAIs, and public meetings, the Staff has comprehensively reviewed the issue of ASR at Seabrook and has appropriately determined that, as conditioned, the LAR should be issued.

The Staff also gathered additional information to support its review of the ASR issue at Seabrook through mechanisms that largely meet the three elements that C-10 asserts constitute a peer review. First, the Staff had the ACRS review the issue. As required by statute, the ACRS is separate from the Staff and reports directly to the Commission.[22] Moreover, the ACRS is composed of highly qualified professionals[23] and, as a part of its review of the ASR issue at Seabrook, it reviewed all of the relevant materials and met with and asked questions of the Staff and NextEra (NRC048 at 1). Second, the Staff office with the responsibility for the review of the LAR, NRR, had a different Staff office, RES, provide its opinion of the validity of the LSTP (INT024, encl. 2 at 30–31). RES assigned this task to Jacob Philip, one of its members with expertise in concrete (NRC006), who reviewed the documentation relevant to the LSTP (NRC005).

For these reasons, C-10's argument regarding peer review and in-house expertise is not persuasive.

CONCLUSION

Q.53. After reviewing all of the information available to you since the issuance of the SE, including all of the information provided by C-10 and Dr. Saouma, is it still your expert opinion that the proposed plant-specific method of evaluation for design evaluation of seismic Category I reinforced concrete structures affected by ASR at Seabrook is, as conditioned, acceptable and provides reasonable assurance that these structures will continue to meet the NRC's requirements?

A.53. Yes.

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[22] 42 U.S.C. § 2039.
[23] *See* https://www.nrc.gov/about-nrc/regulatory/advisory/acrs/membership.html.

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

In the Matter of NEXTERA ENERGY SEABROOK, LLC (Seabrook Station, Unit 1)	Docket No. 50-443-LA-2

AFFIDAVIT OF ANGELA BUFORD

I, Angela Buford, do hereby declare under penalty of perjury that my statements in the foregoing testimony and my statement of professional qualifications are true and correct to the best of my knowledge and belief.

Executed in Accord with 10 CFR 2.304(d)

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Execute in Rockville, Maryland
this 24th day of July 2019

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

In the Matter of NEXTERA ENERGY SEABROOK, LLC (Seabrook Station, Unit 1)	Docket No. 50-443-LA-2

AFFIDAVIT OF BRYCE LEHMAN

I, Bryce Lehman, do hereby declare under penalty of perjury that my statements in the foregoing testimony and my statement of professional qualifications are true and correct to the best of my knowledge and belief.

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this 24th day of July 2019

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

In the Matter of	
NEXTERA ENERGY SEABROOK, LLC	Docket No. 50-443-LA-2
(Seabrook Station, Unit 1)	

AFFIDAVIT OF GEORGE THOMAS

I, George Thomas, do hereby declare under penalty of perjury that my statements in the foregoing testimony and my statement of professional qualifications are true and correct to the best of my knowledge and belief.

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