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November 4, 2013

Allison M. Macfarlane, Chair
Kristine L. Svinicki, Commissioner
George Apostolakis, Commissioner
William D. Magwood, IV, Commissioner
William C. Ostendorff, Commissioner
U.S. Nuclear Regulatory Commission

Mail Stop O-16G4
Washington, DC 20555-0001

Dear Commissioners,

Please find below analysis and commentary by Dr. Paul Brown, Professor of Ceramic Sciences and Engineering, Penn State University, prepared under contract to the Union of Concerned Scientists (UCS).

Dr. Brown's commentary addresses ASR concrete degradation at the Seabrook nuclear power plant and specifically reviews the NRC's inspection report O5OOO443/2012010 (ML 13221A172) concerning the NRC's Confirmatory Action Letter to NextEra Seabrook Energy, LLC dated August 9, 2013.

I have also attached a summary document prepared by the Union of Concerned Scientists and the Newburyport, MA-based C-10 Research & Education Foundation detailing the two organization's concerns and recommendations with regard to the testing, management and mitigation of the ASR concrete degradation at Seabrook.

UCS respectfully requests a detailed response in writing from the NRC to the concerns and recommendations outlined in Dr. Brown's analysis and the UCS/C-10 summary document. We request that you incorporate in your response the actions your agency will take to correct the deficiencies we have identified in NextEra's ASR concrete degradation investigation.

Sincerely,

David C. Wright

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Cc: William M. Dean, Regional Administrator Region One, United States Nuclear Regulatory Commission

Mel Gray, Branch Chief, Engineering Branch One, United States Nuclear Regulatory Commission

Commentary on

SEABROOK STATION, UNIT NO. 1
- CONFIRMATORY ACTION LETTER FOLLOW-UP INSPECTION
- NRC INSPECTION REPORT O5OOO443/2012010 (ML 13221A172)

Paul Brown, Ph.D.[1]
September 29, 2013

Background to the Commentary

The occurrence of the alkali silica reaction (ASR) has been discovered in the concrete at the Seabrook Nuclear Power Generating Station. ASR is an expansive chemical reaction that occurs within concrete and causes the concrete to expand and crack.

On May 16, 2012, the Nuclear Regulatory Commission (NRC) sent NextEra, which owns Seabrook, a Confirmatory Action Letter (CAL) documenting 11 actions NextEra committed to undertake in response to the discovery of ASR at the plant. The Commentary below is in response to the NRC's August 9, 2013 inspection report that follows up on actions in the Seabrook CAL.

When the NRC decides that one of the actions specified in the CAL has been adequately completed, that CAL item is said to be "closed." This Commentary addresses the closure of several CALs at Seabrook, among other things.

While the origin of ASR and its effects on concrete are well understood, there is uncertainty with respect to its effects when the concrete is highly reinforced. Although the presence of internal steel reinforcement is anticipated to resist the growth in the width of cracks in the material, its presence will not limit the progression of the ASR itself. This situation can make it difficult to establish a means for benchmarking the progression of the reaction and the associated damage to the concrete unless concrete samples are extracted from the affected structures and tested.

1) The first area of concern is that NextEra has preferred to use measurements of crack widening (*combined crack indexing*, or CCI) of concrete structures at Seabrook as the primary criterion for establishing the progression of ASR. This is of concern because there is not a well-established basis for relying on this criterion as a reliable measure of damage in highly reinforced concrete.

2) A second area of concern is the lack of predictive capability of CCI measurements when attempting to establish when the concrete in a structure will become incompetent from the point of view of engineering design.

3) A third area of concern is that there is presently no generally accepted technology to mitigate the effects of ASR within an existing concrete structure.

[1] Dr. Brown is an ASR concrete expert at Penn State University who has worked for the National Institute of Standards and Technology (NIST) in Gaithersburg, MD and has advised the NRC. He was a contributor to the newly released report *Codes and Standards for Nuclear Plant Concrete for Nuclear Power Plants*, and is serving on an American Concrete Institute (ACI) ASR Task Group.

Based on these concerns there has been an ongoing interaction between the NRC and NextEra to address these issues. Unfortunately, a number of the documents pertinent to this dialog have not been made available for public commentary.

In the Commentary below:

- Text in Times New Roman font is my commentary on the Aug. 9 NRC inspection report. The numbering below follows the section numbers in the inspection report.
- Text in Arial font is quoted from the Aug. 9 NRC inspection report.

Commentary:

1.0: The NRC report references document FP 100716 in which NextEra cites the lower bound values for structural capacity. It is not clear whether this is the present lower bound attributed to in-place concrete. If so, it is appropriate to state what this is and how it was established. It is reasonable to anticipate that the ultimate lower bound of the structural capacity of the ASR-affected concrete in compression and tension will be that associated with the frictional forces between unbonded aggregate. The Seabrook concrete structures contain lap splices between the embedded reinforcement. A lap slice is formed when sections of rebar are laid parallel to one another but are not physically connected. The theory is that the concrete between the adjacent sections of rebar is strong enough to transfer stresses between them. This ability is reduced when the properties of the concrete are affected. Although NextEra has claimed that concrete properties are not important in and of themselves, this is not true for these situations in particular. **This lower bound would have a significant impact on the integrity of lap splices and anchorage capacity in particular**.

3.0: The NRC report refers to CAL-2, and notes that NextEra summarized two root causes:

> RC1 - The ASR developed because the concrete mix designs unknowingly utilized an aggregate that was susceptible to Alkali-Silica Reaction. Although the testing was conducted in accordance with ASTM standards, those testing standards were subsequently identified as limited in their ability to predict long term ASR.
>
> RC2 - The health monitoring program for systems and structures does not contain a process for periodic reassessment of failure modes that were excluded from the monitoring criteria to ensure that the monitoring/mitigating strategies remain applicable and effective.
>
> Based upon the team's initial review, the inspectors concluded that the second root cause identified was not sufficiently characterized in NextEra's May 24, 2012, submittal. Specifically, NextEra did not clearly describe the performance and organizational factors that contributed to inadequacies in the Structures Monitoring Program (SMP) and the failure of the Seabrook staff to have identified ASR degradation of reinforced concrete structures sooner.

The above statement seems inconsistent with the closure of CAL-2. It is well understood that the occurrence of cracking in a concrete structure, regardless of its genesis, renders that structure susceptible to other forms of deterioration. No systematic analyses appear to have been done on the Seabrook concrete structures to establish the presence or absence of corrosion of embedded steel as a baseline for extrapolating future performance. This seems particularly relevant considering that there is an unresolved issue of potentially aggressive water migration through the concrete via unknown paths.

4.0: The NRC report cites the June 8, 2012 NextEra Corrective Action Plan (CAP) (and May 1, 2013 update (Enclosure 2)) as satisfying CAL-4 by outlining "the major elements of diagnosis, evaluation, prognosis and mitigation of ASR-affected structures."

> The team identified no findings. Based upon the team's review, CAL Item 4 is closed.
>
> NextEra's ASR project staff stated that they plan to maintain the ASR Project CAP as a "living document" and will update it periodically to capture completion of activities and add new actions, as appropriate.

The above statement seems inconsistent with the closure of CAL-4.

5.0: CAL-7 was a NextEra commitment to do prism testing to assess long-term aggregate expansion. However, because the mortar bar test results showed that there was sufficient reactive aggregate to support the continued occurrence of ASR, this test was dropped.

6.0: CAL-8 called for submitting technical details for proposed large-scale testing. This testing is being carried out at the University of Texas (UT) at Austin. Testing has not yet gotten far enough along to provide results. The theoretical basis for the testing is to evaluate ASR-susceptible concrete that is reinforced in two dimensions but not in the third as a model for concrete in the Seabrook structures where similar reinforcement architecture was used. **This type of reinforcement is found in the majority of the Seabrook structures**.

CAL-8 cites back to NextEra's updated Corrective Action Plan of May 1, 2013, which is a document 104 pages in length that lays out, with milestones, the testing protocols being carried out to evaluate ASR at Seabrook.

> No findings were identified. Based upon team review of the submitted testing program documents and related inspection activities, the team concluded that NextEra has provided an appropriate level of detail of the proposed large-scale specimen testing program, and CAL Item 8 is closed.

7.0: CAL-9 is related to a monitoring program.

> Based in part on NRC observations, NextEra issued Revision 3 to the SMP on April 30, 2013. The SMP enhancements are: 1) the addition of periodic (every 30 months) combined crack indexing (CCI) measurements at 72 discrete locations identified as Tier II (Acceptable with Deficiency) areas (CCI values between 0.5 mm/m and 1.0 mm/m, or crack widths greater than 0,2 mm, but less than 1.0 mm) to collect quantitative information on the progression of ASR expansion/degradation (this monitoring was being performed, but not documented in the SMP); and, 2) inclusion of the periodic groundwater sampling program for monitoring of chemical attributes detrimental to concrete structures.

Based on the prior discussion, the value of this program is questionable considering the criteria being applied to what is an acceptable crack. **New cracks of any size should not be forming in such mature concrete structures, regardless of displacement. There is no existing standard that correlates crack displacement in a reinforced structure to the extent of ongoing ASR within that structure.**

Consequently it is a goal of the work at UT-Austin to establish such a correlation:

> The crack growth monitoring provides a visual indication of the progression of ASR within a reinforced concrete structure, The relative width and number of visible cracks may be correlated to the overall progression of ASR and may be used to evaluate ASR impact on structural performance. However, ASR cracking and crack propagation is closely associated with the specific reinforcement design and structural loading. Accordingly, the adequacy of CCI measurement as a long-term structures-monitoring methodology for Seabrook structures is being further evaluated by NextEra as part of the UT-Austin FSEL testing program. The results of the UT-Austin testing program are intended to be used to validate this methodology for application at Seabrook.

NextEra has committed to monitor the ground water chemistry. However, **the present report does not provide any detail as to this program.**

8.0: Regarding CAL-11. NextEra has committed to continue a program of the anchorage capacity of ASR-affected concrete. However, **the present report does not provide any detail as to this program.**

The testing program at UT-Austin will also evaluate the variations in the strength and moduli values of test blocks and cylinders. However, **the present report does not provide any detail as to this program.**

9.0: Previously Identified Issues of Interest

9.1: NextEra identified 26 locations where crack displacement in Seabrook concrete (including the containment structures) have become excessive. This finding requires a detailed structural assessment. However, the **present report does not provide the criterion for defining what constitutes an excessive crack, nor does it provide any detail as to this program.**

> The [NRC inspection] team found [NextEra's] approach of reducing load factors to establish more representative demand loads in order to demonstrate additional margin to assure structural integrity acceptable for the current state of ASR degradation. NextEra plans to credit the load factors in the load demand calculation to establish full qualification per the Final Safety Evaluation Report (FSAR) licensing basis in the final operability determination, following completion of the testing program at UT-Austin.

It is not entirely clear what the forgoing actually means.

For those areas where cracks exceeded 1.5 mm/m, NRC found that the NextEra structural analyses was not adequate and has requested that additional analyses be carried out.

9.2: NextEra is maintaining the position that materials property testing need not be carried out:

> For the long-term, NextEra has elected to evaluate structural performance (operability) of the Seabrook ASR-affected reinforced concrete structures by developing a testing program involving large specimens that are fabricated to closely replicate the Seabrook concrete and reinforcement design. NextEra has pursued this method, instead of conducting detailed material properties

testing of core samples, based upon available laboratory testing and data that indicates that measurable material properties of removed cores do not, under all circumstances, accurately represent the "in situ" mechanical properties of the concrete. The reason for the difference is that prior to removal of the core sample, that concrete specimen is subjected to the specific structural compressive stresses (dead loads, live loads, and hydrostatic loads) and inherent restraint due to reinforcement bars. When removed from the structural member, that concrete specimen is unrestrained. In addition, as identified in the associated core sampling standard (ASTM C42, "Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete"), core sample test results may be "...affected by many factors such as the strength level of the concrete, the in-place temperature and moisture histories, the degree of consolidation, batch-to-batch variability, the strength-gain characteristics of the concrete, the condition of the coring apparatus, and the care used in removing cores."

It is well understood that drilled cores are extracted from an existing structure and have been subjected to the service environment associated with that structure. This in no way invalidates the result of the testing. The NextEra preposition misuses the cautionary language of ASTM C42 and appears to be an attempt to avoid accumulating data which might be regarded as problematic.

NextEra has committed to extract and test additional cores. However, the **present report does not provide any detail as to this program.**

9.3: This section states that ASR causes chemical prestressing. Such a statement indicates a misunderstanding of prestressing. In prestressing, steel reinforcement is placed in tension prior to concrete placement. When the tension is removed the steel places the concrete in compression to reduce cracking. This is remote from the conditions within ASR-affected concrete.

The present report indicates an assessment of the extent of stress presently affecting the reinforcement and cites that the steel is not being plastically deformed.

9.4: No evidence of rebar corrosion has been found.

9.5: The large-scale testing program is designed to establish the probability of mid-wall cracking that is not amendable to being detected by inspections of surface cracks. However, **this assessment should also be carried out on the actual in-place concrete.**

9.6: This section indicates that NRC staff finds the use of the CCI as an acceptable method of conditional assessment. This is unfortunate because it does not encourage NextEra to apply NDE techniques or other (assessment) techniques to quantify conditional analyses.

The CCI index indicates continued ASR-induced expansion to be occurring in the Seabrook concrete.

In the ASR Crack Index Report (FP10081 1), NextEra measured CCI values for 26 locations in the monitoring program and compared the results to the data taken in June 2012. The December CCI data shows an apparent increase in most (19 of 26) of the monitored locations. NextEra concluded the apparent increase in CCI values may be due to seasonal temperature variations because the concrete (in December) was significantly colder, which may cause the concrete to contract between the cracks, increasing the apparent crack widths, This assumption is unfounded. If the physical dimensions of a structure containing cracks are decreasing, the crack displacements will also decrease.

The inconsistencies between pin expansion data and the CCI data show the complexity of interpreting the results of the analyses being conducted.

12: Based on a NextEra assumption that ASR would only be limited to below grade concrete, an aircraft impact analysis was done. The assumption that ASR will be limited to below grade concrete is unfounded. **The assumption that aircraft impact will not transfer stresses to ASR compromised concrete is unfounded.**

Prepared under contract with the Union of Concerned Scientists

Union of Concerned Scientists

Continuing Problems with Monitoring Concrete Damage at Seabrook[1]

November 4, 2013

Concrete degradation by alkali silica reaction (ASR) has been discovered in several structures at the Seabrook Nuclear Power Generating Station. ASR is a chemical reaction that causes the expansion of materials in the particular concrete used at Seabrook, which causes the concrete to crack. Over time it can weaken the concrete and cause steel reinforcing rods embedded in the concrete to corrode and weaken.

Seabrook is the first nuclear plant in the U.S. fleet in which ASR concrete degradation has been discovered. Currently there is no existing technical or regulatory basis for this adverse condition.

On October 9, the NRC released a letter closing out its May 16, 2012 Confirmatory Action Letter to NextEra, which contained activities related to understanding concrete degradation at the Seabrook nuclear plant.

After reviewing the NRC inspection reports, we question whether NextEra has successfully fulfilled some of these action items. The attached commentary by concrete expert Dr. Paul Brown discusses some of these issues.

More importantly, there are fundamental issues that continue to plague the testing and inspection process at Seabrook. These severely limit the ability to understand the current extent of the concrete degradation, to develop adequate monitoring of the deterioration over the next several decades, and to devise processes for countering the deterioration and maintaining structural integrity at Seabrook.

This is important since the license extension that NextEra is requesting would allow Seabrook to operate for another 37 years (until 2050). This is longer than the 30 years the concrete has currently been in place (construction was completed in 1986). Additional ASR damage during this future period could be very significant since chemical studies of the concrete at Seabrook show that the ASR reaction and expansion will continue.

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[1] This report was compiled with the assistance of Dr. Paul Brown of Penn State University who is an ASR concrete expert who has worked for the National Institute of Standards and Technology (NIST) in Gaithersburg, MD and has advised the NRC. He was a contributor to the newly released report *Codes and Standards for Nuclear Plant Concrete for Nuclear Power Plants*, and is serving on an American Concrete Institute (ACI) ASR Task Group.

Since there is currently no generally accepted technology to mitigate the effects of ASR within an existing concrete structure, the best one can do is to monitor and understand the evolution of the structural damage. As a result, developing and applying reliable methods of ongoing monitoring is crucial.

But it is important to recognize that at this point the NRC and NextEra are still assessing the situation at Seabrook to understand the current extent and potential consequences of the ASR problem. There have been no meaningful analyses to determine how fast the concrete will degrade or to develop a plan for repairing the concrete.

Fundamental problems with inspections at Seabrook

We raised several key issues in previous commentaries on the concrete tests at Seabrook that have still not been addressed and that raise important questions about the testing and analysis that NextEra and NRC are conducting.

(1) Continuing Use of an Unjustified Measure of ASR

NextEra continues to use a "crack index" that only considers crack widths as the parameter characterizing ASR damage. However, there is not a well-established basis for relying on crack widths as a reliable measure of the extent of ASR and damage in highly reinforced concrete.

This is because steel reinforcement bars in the concrete may reduce the growth in the width of cracks in the concrete, but will not limit the progression of the ASR itself. The result of the ASR expansion may therefore be the creation of dense networks of microcracks. This deterioration of the material can weaken the concrete but may not show up as large surface cracks. As a result, an index that instead reflects the total lengths of cracks is expected to be a more reliable indicator of the extent of ASR.

Indeed, the August 9, 2013 NRC inspection report (pp. 14-15) notes inconsistencies found in tests at Seabrook between the crack-width index NextEra uses and other measures of concrete expansion due to ASR, which calls into question the reliability of using crack width as a meaningful measure of ASR progress.

In addition, a crack-width index has not been shown to be predictive of when a structure has been compromised to the point that the structure becomes vulnerable to failure.

The NRC should not accept the continued use of a crack-width index as a primary measure of ASR damage. Key to effective monitoring the future progression of ASR is identifying a meaningful parameter or set of parameters, and this important first step has not yet been successfully taken.

(2) Failure to Adequately Use Core Testing

Observing surface damage of a concrete structure is not a reliable way to understand the extent of damage that has occurred within the body of the concrete. This is especially true in concrete with internal reinforcing bars, which constrain crack widths but do not limit the progression of the ASR. As a result, there is currently no reliable way of assessing the extent of ASR and the resulting damage to the concrete without extracting and testing core sample from the affected concrete structures.

However, NextEra has decided not to use core testing to assess the material properties of concrete structures at Seabrook. It states that core tests are not useful because cores removed from the bulk concrete "are no longer subject to the strains imposed by the ASR-related expansion or restraints imposed by the steel reinforcing cage" and therefore may not give an accurate picture of the structural damage (8/9/13 NRC report, p.1). However, these issues have long been understood by concrete experts. Commenting on this, Dr. Brown writes:

> "It is well understood that drilled cores are extracted from an existing structure and have been subjected to the service environment associated with that structure. This in no way invalidates the result of the testing. The results of core testing are generally understood within the relevant engineering community. The NextEra preposition misuses the cautionary language of ASTM C42 and appears to be an attempt to avoid accumulating data which might be regarded as problematic."

Core extraction is an inexpensive test that allows assessment of compressive and tensile properties. Core samples should be extracted from the affected concrete and compared with cores taken from unaffected concrete in the same structure.

Unfortunately, the NRC has not required NextEra to conduct core testing at Seabrook. The NRC has also not required testing of in-place concrete to assess the adequacy of the anchorage systems that are in place in the operating utility buildings at Seabrook.

(3) Problems with Applying Results of "Replica Testing" to Seabrook

Instead of using core tests, NextEra is planning to rely instead on "replica tests" being conducted at the University of Texas. These tests use concrete samples that are intended to closely resemble the specific concrete used at Seabrook, with the goal of providing "sufficient data and insights to establish the current and future implications of ASR on Seabrook reinforced concrete structures" (8/9/13 NRC report, p.5). The NRC appears to be satisfied with this approach.

However, based on what he has learned about the University of Texas study, Dr. Brown has identified significant problems that limit its application to the Seabrook situation.

First, a major limitation is that the specific concrete materials originally used in the Seabrook concrete are no longer accessible from the quarry, so instead materials from another source are being used for the tests in Texas. Yet the behavior of the concrete depends on the specific chemical composition of the materials in it. The NRC therefore cannot assess how relevant the tests are to the situation at Seabrook until an expert (an "aggregate petrographer") compares the materials in the concrete in Seabrook and that being used in the Texas tests. To our knowledge, such testing has not been done.

The publicly available information does not provide, for example, information on the methods of aggregate grading and sizing, on strength characteristics of the model concrete and the original concrete, and on the curing conditions of the model concrete compared to that of the original concrete—all of which are important to assess the applicability of the Texas results to Seabrook. The NRC inspectors need to understand all of these issues in detail before they can assess the relevance of the Texas study.

Understanding these issues is important enough that tests should also be carried out on the actual in-place concrete at Seabrook. A better way to do these studies may be to use concrete from buildings constructed for a second reactor at Seabrook that was never completed. Such tests are likely to provide more confidence in the applicability of the results than the Texas study.

(4) Misunderstanding of the Structural Role of Concrete in Layered Construction

NextEra argues that because of the steel reinforcing bars embedded in the concrete, assessing the mechanical properties of the concrete itself is not important in understanding the mechanical properties of the overall structure. However, that is not true for layered structures like those at Seabrook.

Many of Seabrook's structures consist of planar layers of reinforcing rods surrounded by concrete, with layers stacked on top of each other without the steel reinforcements running in the third direction to tie the layers together. As a result, it is the concrete between the layers that tie them together. Therefore, the strength of the overall structure will depend on the strength of the concrete that binds the layers together. Weakening of the concrete will therefore weaken the structure.

The Texas studies will attempt to look at this issue, but as noted above, the applicability of those tests to Seabrook must be established.

(5) Lack of Information on Corrosion of Steel Reinforcing Bars at Seabrook

As noted above, NextEra sees embedded steel reinforcement bars as playing the major role in determining the structural properties of concrete structures. NextEra has stated it believes steel within the concrete has not corroded, and NRC inspectors have accepted this conclusion based in part on examination of a limited number of Seabrook rebar (8/9/13 NRC report, p.12). Yet Dr. Brown notes that:

> "No systematic analyses appear to have been done on the Seabrook concrete structures to establish the presence or absence of corrosion of embedded steel as a baseline for extrapolating future performance. This seems particularly relevant considering that there is an unresolved issue of potentially aggressive water migration through the concrete via unknown paths."

If the water that has infiltrated the concrete to cause ASR contains chloride and/or sulfate, it can result in corrosion of the embedded steel structures. That is because both chemicals can lead to "depassivation," meaning that they can break down the usual protective layers that form around steel in concrete, and therefore result in corrosion of the steel.

This is a concern since studies of the ground water at Seabrook reported in 2010 (p.32) indicate that both chloride (19 to 3900 ppm) and sulfate (10 to 100 ppm) are present. While some questions have been raised about these results, this remains an important unresolved issue. Even low-level concentrations of chloride (100 ppm or less) can lead to the corrosion of embedded steel.

Assessing the chemistry of the ground water at Seabrook and what corrosion of steel has occurred to date is crucial for understanding the current status and potential future degradation of concrete structures at Seabrook.

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Joosten, Sandy

From: Sean Meyer <SMeyer@ucsusa.org>
Sent: Monday, November 04, 2013 1:36 PM
To: CHAIRMAN Resource; CMRSVINICKI Resource; CMRAPOSTOLAKIS Resource; CMRMAGWOOD Resource; CMROSTENDORFF Resource
Cc: OPA Resource; Dean, Bill; Gray, Mel; Woollen, Mary; David Wright; debbie@c-10.org; Dave Lochbaum; Sean Meyer
Subject: ASR concrete degradation, Seabrook
Attachments: UCS-Seabrook letter 11-4-13.pdf; UCS_C-10 Seabrook_Concrete_11-4-13.pdf

November 4, 2013

Dear Commissioners,

Please find attached an electronic version of a letter to the Commission from David Wright, co-director of the Global Security program at the Union of Concerned Scientists (UCS) concerning ASR concrete degradation at the Seabrook nuclear power plant in New Hampshire. In this same document, there follows an analysis and commentary by Dr. Paul Brown, Professor of Ceramic Sciences and Engineering, Penn State University, who has been contracted by UCS. Also attached is a summary document prepared by UCS and the Newburyport, MA-based C-10 Research & Education Foundation detailing the two organization's concerns and recommendations with regard to the testing, management and mitigation of the ASR concrete degradation at Seabrook. Thank you.

Regards,

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