Continuing Problems with Monitoring Concrete Damage at Seabrook[1]

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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.

Contacts:

Sandra Gavutis
Executive Director
C-10 Research and Education Foundation
44 Merrimac St.
Newburyport, Ma. 01950
(978) 465-6646
sandra@c-10.org

Dr. David Wright, Co-Director
Global Security Program
Union of Concerned Scientists
Two Brattle Square, Suite 600
Cambridge, MA 02138
(617)-301-8060
dwright@ucsusa.org