Sengupta, Abhijit

From: Williams, Charles R. [Charles.Williams@pgnmail.com]
Sent: Thursday, December 31, 2009 2:52 PM
To: Lake, Louis; Thomas, George; Carrion, Robert
Subject: FW: Fm 5.2 Draft for Review
Attachments: FM 5.2 Exhibit 2 - Mactec PetrographicReport-Final NO PHOTOS.pdf

16 pages

Resending Exhibit 2 separately due to file size.

From: Williams, Charles R.
Sent: Thursday, December 31, 2009 2:41 PM
To: 'louis.lake@nrc.gov'; 'George.Thomas2@nrc.gov'; 'nausdj@ornl.gov'; 'rpc1@nrc.gov'
Subject: Fm 5.2 Draft for Review

Mr Lake and others,

Attached for you review is the draft of FM 5.2 and its exhibits. If you have any comments or questions, please contact me or Craig Miller.

Thank you,
Charles Williams
919-516-7417

P/127

FM 5.2 Exhibit 2

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engineering and constructing a better tomorrow

November 11 2009

Mr. Craig Miller
Progress Energy
(352) 795-6486 ex 1026
Craig.miller@pgnmail.com

Subject: **Report of Petrographic Observations**
Crystal River Containment Wall
Steam Generator Replacement Project
Crystal River Nuclear Generating Facility, Florida
MACTEC Project No. 6468-09-2535

Dear Mr.

MACTEC Engineering and Consulting, Inc. (MACTEC) is pleased to present this report of our petrographic observations performed on two concrete cores that were shipped to our laboratory under chain of custody. An additional core was received under chain of custody for limited observations. It is our understanding the two cores submitted for petrographic observations are from an area of the containment wall where a fracture was discovered running parallel to the surface at a depth of approximately 8 to 9 inches. We understand the core that was submitted for limited observations was from an area where the subject fracture had not occurred.

The cores submitted are as follows:

Core Number	Laboratory Number Assigned by MACTEC	Description of the Core
5	21269	From an area where the fracture had occurred
2	21270	From an area where the fracture had not occurred
7	21271	From an area where the fracture had occurred

Each core was photo documented as received and then saw cut longitudinally into halves. Each half was labeled with the same sample number and than A and B were added to designate the halves. As requested the B half for cores 21269 and 21270 were shipped to CTL Group in Skokie Illinois. The B half of core 21271 is being held for possible future use. The A half's of the cores were used for our analysis.

The purpose of our work was to perform a petrographic analysis of samples 21269A and 21271A and limited observations of sample 21270A. It is our understanding that you also require specific information relative to the age of the fractured surfaces on samples 21269A and 21271A. Sample 21270A was used as a control sample that did not have a fractured surface.

Petrographic Observations

A Petrographic Analysis is a visual and microscopic analysis of cementitous materials performed by a qualified petrographer. Petrographic examinations are typically performed on polished sections or thin sections. Polished sections are generally cut sections that have been lapped (ground flat and smooth) and polished and are observed using reflected polarized light microscopes at magnifications of up to 80X. Thin sections are samples mounted to glass slides and ground to specific thicknesses (generally 20, 30, or 40 microns depending on the application) and observed using transmitted polarized light microscopes at magnifications of up to 600X.

A petrographic evaluation may be performed to identify and describe a specific item of interest such as the presence or extent of distress in concrete, or to provide a general characterization and measure of quality of the materials being evaluated. The petrographic evaluation of concrete examines the constituents of the concrete including coarse aggregates, fine aggregates, embedded items, hardened paste, and air void structure. The examination identifies cracking present in the concrete, indications of corrosion, extent of damage from external sources, aggregate reaction, chemical attack, sulfate attack, freeze thaw cracking, acid attack, and other mechanisms of deterioration. The petrographic examination can also estimate the water to cement ratio, look for indications of mineral additives and unhydrated cement particles in the paste, look for indications of bleed water and excess porosity in the concrete, look for indications of curing procedures used and methods of finishing, observe micro cracking present and other conditions within the concrete which might give information on the overall quality or the quality of any particular constituent material. Aggregate mineralogy, rock types, and mineral crystal structure can be identified when thin sections are viewed under a transmitted polarized light microscope.

TEST RESULTS AND OBSERVATIONS

PETROGRAPHIC OBSERVATIONS

The petrographic analysis was performed in general accordance with the applicable sections of ASTM C 856-04 Standard Practice for Petrographic Examination of Hardened Concrete. The results of our petrographic analysis are on the attached sheets, Summary of Petrographic Observations of Hardened Concrete. Photographs from our examination are attached. A summary of our observations and discussion are as follows.

Aggregate

The coarse aggregate generally consisted of a natural carbonate crushed rock with a maximum size of 3/4 inch. The rocks types observed included limestone, fossiliferous limestone, and a few particles of chert and/or limestone and chert. The particles were generally angular to sub-rounded in shape and fairly evenly distributed. The coarse aggregate appeared to comprise approximately 50% of the total aggregate quantity with the remaining fraction being fine aggregate.

On sample 21271, there were 4 coarse aggregate pieces on the cut surface of the core that retained moisture (and moisture in the surrounding paste) longer than other portions of the sample. These pieces are shown in Photographs 5, 6, 7, and 8. One of the pieces (Photograph 5 for core 21271) had a darkened rim. A thin section was prepared from the piece in photograph 7 and this piece contained microcrystalline quartz and radial silica and exhibited localized evidence of alkali silica reaction.

The fine aggregate was observed to be a natural siliceous sand consisting mostly of quartz. The particles were generally sub-angular to sub-rounded in shape and fairly evenly distributed.

Cement Paste

The cement paste was medium light gray (Reference colors from The Geological Society of America Rock-Color Chart, 1991). The paste appeared moderately hard and not easily scratched with a hardened steel point. The concrete appeared to have been placed at a moderately low water to cement ratio, possibly in the range of 0.4 to 0.5. Indication of placement at a high water to cement ratio such as significant bleed channels and water gain voids were not observed.

Air Voids, Voids, and Cracks

The concrete appeared to be air entrained and had a total air content estimated to be around 2 to 3%. The voids were generally small and spherical. Some air void clustering was observed around a few coarse aggregate particles. The air void distribution was moderately un-even and some small areas lacked air entrainment. There was limited mineral growth observed in some of the air voids. Calcium hydroxide was observed lining some air voids.

SPECIFIC OBSERVATIONS OF THE FRACTURED SURFACE ON SAMPLES 21269A AND 21271A

Observations of fractured surface on sample 21269A

- The edge of the fractured surface had sharp distinct edges.
- Generally the coarse aggregate (predominately limestone) fractured as opposed to being pulled out of the cement paste matrix.
- The fine aggregate (predominately quartz) generally was pulled out of the cement paste although it appeared that a few pieces of the quartz did fracture.
- The paste portion of the fractured surface did not appear carbonated and produced a pink color when phenolphthalein was applied.
- Some of the air voids that were exposed on the fractured surface had some mineral grown in them. We did not observe the mineral growth on the fractured surface around these subject voids.
- Pieces of this sample were purposely fractured in our laboratory and the purposely fractured surfaces had similar observations to the submitted fractured surface.
- There was a white colored deposit on a few areas of the fractured surface. The deposit was easily scratched off and contained desiccation cracking. Based on our observations of immersion mounts viewed under a petrographic microscope the deposit appeared to contain very fine material and small sharp angular pieces of quartz. These observations are consistent with what we would expect from core drilling slurry.

Observations of fractured surface on sample 21271A

- The edge of the fractured surface had sharp distinct edges.
- Generally the coarse aggregate (predominately limestone) fractured as opposed to being pulled out of the cement paste matrix.
- The fine aggregate (predominately quartz) generally was pulled out of the cement paste although it appeared that a few pieces of the quartz did fracture.
- The paste portion of the fractured surface did not appear carbonated and produced a pink color when phenolphthalein was applied.
- Some of the air voids that were exposed on the fractured surface had some mineral grown in them. We did not observe the mineral growth on the fractured surface around these subject voids.
- Pieces of this sample were purposely fractured in our laboratory and the purposely fractured surfaces had similar observations to the submitted fractured surface.

METHODOLOGIES TO EVALUATE THE RELATIVE AGE OF CONCRETE CRACKS

Several articles have been written about dating cracks by measuring carbonation. Carbonation is a reaction that takes place between hydroxides in the cement paste and carbonic acid. The carbonic acid reacts with the alkaline components (the hydroxides) in the cement paste and neutralizes them. The carbonic acid can be derived from the dissolution of atmospheric carbon dioxide (CO_2) in the concrete pore water. Generally, the longer the concrete is exposed to the atmosphere the greater the depth of carbonation.

In Adam Neville's article, Can We Determine the Age of Cracks by Measuring Carbonation?, Mr. Neville states in his conclusions that "On the basis of carbonation measurements and of direct observation, it is often possible to say that a crack is old, but it is not possible to say that it is new". Mr. Neville also states "If very little carbonation has taken place, then this can be due to one of two reasons: either the crack is new or the conditions of exposure were such that carbonation could not proceed."

In the article, Carbonation as an Indicator of Crack Age by Dipayan Jana and Bernard Erlin, the authors state that "...carbonation can, at best be used as a qualitative measure of crack age. In most cases, however, determining the age of a crack by measuring the depth of carbonation along its walls is highly unreliable..." The authors present some alternative crack age indicators as follows:

- Cracks spanned by bridges of paste indicate they were formed when the concrete was semi-plastic.
- Crack surfaces that are smooth indicate they were formed before concrete had attained much strength.
- Cracks that intersect air voids and pass through secondary deposits indicate formation after the deposit precipitates.
- Where 2 cracks intersect and one contains secondary deposits, the crack containing secondary deposits is usually older.

Additionally, in the book Concrete Petrography by Donald A. St. John, Alan W. Poole an Ian Sima, the authors point out that Concrete cracks in the hardened state, but can only form channels, fissures and voids in the plastic state before setting.

DISCUSSION

In general the concrete appeared to be in good condition. There was some evidence that the chert particles are undergoing alkali silica reaction however significant distress due to alkali silica reaction was not observed in the samples and the chert particles comprised a very small percentage of the aggregates. It is not unusual to see evidence of some alkali silica reaction in older concrete.

We understand the original mix design used for the project (copy attached) specified approximately 37% sand and 63% coarse aggregate. Based on our observations of the core samples we estimate they contained approximately 50% sand and 50% coarse aggregate. The mix design indicated a water to cement ratio of 0.38. Based on our observations of the core samples we estimate the water to cement ratio may have been on the order of 0.4 to 0.5. However, the evaluation of water to cement ratio of older concrete is very subjective and may not be reliable.

Based on the sharp distinct edge of the fractured surface, observations of fractured coarse aggregate (limestone, which is relatively easy to fracture), the observations of a few fractured fine aggregate (quartz, which is relatively hard to fracture) pieces we expect the fractured surface observed in the samples occurred after the concrete had hardened and attained significant overall strength as well as sufficient paste-to-aggregate bond to enable failure in the limestone aggregate.

It is our understanding that the subject crack was an internal crack and not readily exposed to the atmosphere. The outside surfaces had some levels of carbonation but the cracked surfaces did not. We expect the lack of observed carbonation on the crack surface could be due either to the lack of sufficient CO_2 in the crack space to cause carbonation even though a long period of time could have elapsed since cracking or the crack was recently formed even though sufficient CO_2 was available If the cracked surface had been carbonated, that would indicate that there was sufficient CO_2 to initiate carbonation and sufficient time had elapsed for the carbonation to progress into the concrete. In the case of these concrete samples and the expected exposure condition of the crack surface, the lack of observed carbonation on the fractured surface of the samples is inconclusive regarding an estimate on the age of cracking.

A significant observation on the fractured surfaces of the samples is the mineral growth that was observed in some of the air voids exposed at the fractured surface, but mineral growth was not observed on the fractured surface. There was not an extensive amount of mineral growth observed in the voids indicating the concrete was relatively dry in service (possibly due to the elevated temperature inside the containment area). Had the crack been in existence for a long period of time, we would have expected to see some mineral growth on the fractured surface.

SUMMARY

The lack of carbonation on the fracture surface is inconclusive with respect to dating the cracks. Our findings indicate either the crack is relatively new or the crack could be old but the atmosphere the crack was exposed to (an internal fracture not exposed to the outside atmosphere) was not conducive to carbonation.

The fractured limestone coarse aggregate particles on the fractured surface indicate the concrete had gained sufficient strength and bond with the coarse aggregate to prevent aggregate pull-out and cause the fracturing. The limestone coarse aggregate generally does not have a high tensile strength and is expected to fracture relatively easily. A few of the quartz fine aggregate particles had fractured indicating the concrete had gained sufficient strength and bond with a few of the fine aggregate particles to cause fracturing. The quartz fine aggregate generally has a relatively high tensile strength. The fractured aggregates indicate the fractured surface of the samples probably did not occur soon after the concrete placement when the concrete was relatively fresh. We understand this member is post-tensioned and it is likely that the tendons were tensioned weeks following the placement after sufficient strength gain for P/T tensioning was attained but still relatively early in the service life. We anticipate the cracking occurred after this stage however exact correlation to this occurrence/ load induced cracking was inconclusive based on the findings. Dating the crack based on observations of aggregate fracture was inconclusive beyond a period of after post-tensioning to relatively new/recent crack occurrence.

The mineral growth that was observed in some of the air voids exposed at the fractured surface, but was not observed on the fractured surface indicates the air voids have existed longer than the fractured surface. Obviously the air voids have been there since the concrete was in a plastic state and over time under favorable conditions, the mineral growth in the voids has occurred. Had the crack been in existence for a long period of time, we would have expected to see some mineral growth on the fractured surface. The lack of mineral growth on the fractured surface of the samples indicates the crack is either relatively new or occurred after favorable conditions for mineral growth were diminished.

Had carbonation or mineral growth been observed on the fracture surface of the samples, that would have indicated the crack is relatively old. The lack of carbonation and mineral growth on the fracture surface of the samples is an indication that either the crack could be relatively new or the conditions for carbonation and mineral growth had not been favorable since the crack developed, in which case the age of the crack could not be determined.

We trust this information meets your current needs. If more information is needed of if you have any questions, please contact us.

Sincerely

MACTEC ENGINEERING AND CONSULTING, INC.

for David C. Wilson with permission
Senior Principal Professional

Ufuk Dilek Ph.D.
Senior Principal Professional

(2 copies submitted)

Attachments: References
Summary of Petrographic Observations for Cores 21269A and 21271A
Photographs for Samples 21269 and 21271
Reports from Pittsburgh Testing Laboratory

CITED REFERENCES

Neville, A.M., Can We Determine the Age of Cracks by Measuring Carbonation? Part 1, Concrete International, December 2003.

Neville, A.M., Can We Determine the Age of Cracks by Measuring Carbonation? Part 2, Concrete International, January 2004.

Jana, Dipayan, and Erlin, Bernard, Carbonation as an Indicator of Crack Age, Concrete International, May 2007.

St. John, Donald A, Poole, Alan W, and Sims, Ian, Concrete Petrography, John Wiley and Sons, pp 229-246, 1998.

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SUMMARY OF PETROGRAPHIC OBSERVATIONS OF HARDENED CONCRETE – ASTM C-856-04

PROJECT NAME	Crystal River Core Petrography Project
PROJECT NUMBER	6468-09-2535
DATE SAMPLED RECEIVED	10-21-09
SAMPLE I.D.	21269A
SAMPLE SIZE AND DESCRIPTION AS RECEIVED	Concrete core, approximately 3 ¾ inches in diameter, approximately 7 to 8 inches long.
OBSERVATIONS BY	David Wilson

CHARACTERISTICS	*OBSERVATIONS*
COARSE AGGREGATE:	
Shape	Angular to sub rounded
Grading	Approximately ¾ maximum size
Distribution	Even. Approximately 50% of the aggregates appeared to be coarse aggregates with the remaining fraction being the fine aggregate.
Texture	Fine
Composition	Carbonate
Rock Types	Limestone, fossiliferous limestone
Alteration: - Degree - Products	Not observed
Coatings	Not observed
Rims	Not observed
Internal Cracking	Generally not observed except in the vicinity of the fractured surface
Contamination	Not observed
FINE AGGREGATE:	
Shape	Generally sub-rounded to sub-angular
Grading	#4 and smaller
Distribution	Even
Texture	Fine
Composition	Siliceous

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Rock Types	Quartz
Alteration: - Degree - Products	Not Observed
Coatings	Not Observed
Rims	Not Observed
Internal Cracking	A few internal fractures were observed
Contamination	Not observed

CHARACTERISTICS	***OBSERVATIONS***
CONCRETE:	
Air-Entrained or Not	Appeared to have some air entrainment. Total air content based on visual observations appeared to be 2 to 3%
Air Voids: - Shape - Size - Distribution	Mostly small and spherical. Some air void clustering was observed around a few coarse aggregate particles. The air void distribution was moderately un-even, some small areas lacked air entrainment. There was some limited mineral growth observed in some of the air voids. Calcium hydroxide was observed lining some air voids.
Bleeding	Not Observed
Segregation	Not Observed
Aggregate-Paste Bond	Coarse and fine aggregates appeared to have a good bond to the cement paste with few openings. Some aggregate particles had increased calcium hydroxide in the paste surrounding the perimeter of the particle.
Fractures	One end of the core contained a fractured surface. There were some other minor fractures on the end with the fractured surface. On the fractured surface there was a white deposit in a few areas. The deposit exhibited desiccation cracking and appeared to contain fine cement paste particles and some angular quartz fragments. This deposit is expected to be drilling slurry.
Embedded Items - Shape - Size	Not observed

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- Location - Type	
Alteration: - Degree & Type - Reaction Products - Location - Identification	Not observed
Nature and Condition of Surface Treatments	There appeared to be white paint on the exterior surface of the core
Estimated water-cement ratio (based on visual observations only)	Appeared to have a moderately low w/c ratio possibly in the range of 0.4 to 0.5
Estimated cement content (based on visual observations only)	Appeared to have a moderately high cement content
PASTE:	
Color (GSA rock color chart 1991)	Medium light gray
Hardness	Appeared moderately hard when scratched with a hardened steel point
Porosity	Did not appear very porous. It took from 10 minutes to over 20 minutes to absorb 15 micro liter drops of water.
Carbonation	The outer ¼ to ½ inch of the exterior surface was carbonated. The fractured surface was not carbonated.
Residual un-hydrated Cement: - Distribution - Particle Size - Abundance - Composition	Some un-hydrated/partially hydrated cement particles were observed
Mineral Admixtures: - Size - Abundance - Identification	Fly-ash was not observed
Contamination: - Size - Abundance - Identification	Not observed

Equipment Used:

Cannon EOS Digital Rebel with 50mm macro lens and microscope adapters
AmScope 7X to 45X stereo zoom microscope (with and without polarized light)
Olympus BH-2 polarized light microscope
Zeiss Photomicroscope II polarized light microscope
Aven Digital Microscope
Starrett 6 inch rule SN 109000003

Note: No M&TE used is subject to calibration requirements.

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SUMMARY OF PETROGRAPHIC OBSERVATIONS OF HARDENED CONCRETE – ASTM C-856-04

PROJECT NAME	Crystal River Core Petrography Project
PROJECT NUMBER	6468-09-2535
DATE SAMPLED RECEIVED	10-25-09
SAMPLE I.D.	21271A
SAMPLE SIZE AND DESCRIPTION AS RECEIVED	Concrete core, approximately 3 ¾ inches in diameter, approximately 7 to 8 inches long.
OBSERVATIONS BY	David Wilson

CHARACTERISTICS	*OBSERVATIONS*
COARSE AGGREGATE:	
Shape	Angular to sub rounded
Grading	Approximately ¾ maximum size
Distribution	Even. Approximately 50% of the aggregates appeared to be coarse aggregates with the remaining fraction being the fine aggregate.
Texture	Fine
Composition	Carbonate, a few with siliceous deposits
Rock Types	Mostly limestone and fossiliferous limestone. 4 coarse aggregate particles on the cored surface retained moisture much longer than the other particles and one of these particles had a darkened rim
Alteration: - Degree - Products	Not observed
Coatings	Not observed
Rims	Not observed except for one particle
Internal Cracking	Generally not observed except in the vicinity of the fractured surface. One of the particles that retained moisture longer than the other particles (referenced in rock type section) was observed in thin section and contained microcrystalline quartz and

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	radial silica (essentially chert) with the limestone, several cracks were observed going through the portion which was predominately chert. There appeared to be minor amounts of ASR gel but a positive identification could not be made due to the small amounts present.
Contamination	Not observed
FINE AGGREGATE:	
Shape	Generally sub-rounded to sub-angular
Grading	#4 and smaller
Distribution	Even
Texture	Fine
Composition	Siliceous
Rock Types	Quartz
Alteration: - Degree - Products	Not Observed
Coatings	Not Observed
Rims	Not Observed
Internal Cracking	A few internal fractures were observed
Contamination	Not observed

CHARACTERISTICS	***OBSERVATIONS***
CONCRETE:	
Air-Entrained or Not	Appeared to have some air entrainment. Total air content based on visual observations appeared to be 2 to 3%
Air Voids: - Shape - Size - Distribution	Mostly small and spherical. Some air void clustering was observed around a few coarse aggregate particles. The air void distribution was moderately un-even, some small areas lacked air entrainment. There was some limited mineral growth observed in some of the air voids. Calcium hydroxide was observed lining some air voids.
Bleeding	Not Observed
Segregation	Not Observed
Aggregate-Paste Bond	Coarse and fine aggregates appeared to have a good bond to the cement paste with few openings. Some aggregate particles had increased calcium hydroxide in the paste surrounding the perimeter of the

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	particle.
Fractures	One end of the core contained a fractured surface. There were some other minor fractures on the end with the fractured surface. There were some fractures associated the chert particle discussed previously.
Embedded Items - Shape - Size - Location - Type	Not observed

Alteration:
- Degree & Type
- Reaction Products
  - Location
  - Identification
	Not observed

Nature and Condition of Surface Treatments	There appeared to be white paint on the exterior surface of the core
Estimated water-cement ratio (based on visual observations only)	Appeared to have a moderately low w/c ratio possibly in the range of 0.4 to 0.5
Estimated cement content (based on visual observations only)	Appeared to have a moderately high cement content
PASTE:	
Color (GSA rock color chart 1991)	Medium light gray
Hardness	Appeared moderately hard when scratched with a hardened steel point
Porosity	Did not appear very porous. It took from 10 minutes to over 20 minutes to absorb 15 micro liter drops of water.
Carbonation	The outer ¼ to ½ inch of the exterior surface was carbonated. The fractured surface was not carbonated.
Residual un-hydrated Cement: - Distribution - Particle Size - Abundance - Composition	Some un-hydrated/partially hydrated cement particles were observed
Mineral Admixtures: - Size - Abundance - Identification	Fly-ash was not observed
Contamination: - Size - Abundance - Identification	Not observed

Equipment Used:

Cannon EOS Digital Rebel with 50mm macro lens and microscope adapters
AmScope 7X to 45X stereo zoom microscope (with and without polarized light)
Olympus BH-2 polarized light microscope
Zeiss Photomicroscope II polarized light microscope
Aven Digital Microscope
Starrett 6 inch rule SN 109000003

Note: No M&TE used is subject to calibration requirements.