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December 8, 2009

Mr. Craig Miller
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Subject: **Report of Petrographic Observations**
Crystal River Containment Wall and Dome Concrete Samples
Steam Generator Replacement Project
Crystal River Nuclear Generating Facility, Florida
MACTEC Project No. 6468-09-2535

Reference: **Report of Petrographic Observations**
Crystal River Containment Wall and Dome Concrete Samples
Steam Generator Replacement Project
Crystal River Nuclear Generating Facility, Florida
MACTEC Project No. 6468-09-2535
Dated November 11, 2009

Dear Mr. Miller:

MACTEC Engineering and Consulting 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. One core, Core #7 (MACTEC laboratory number 21271A), was previously analyzed and the results were contained in our November 11, 2009 report. An additional core, identified as core #87 was received under chain of custody for petrographic analysis. Core #87 was assigned MACTEC laboratory number 21329. It is our understanding that sample 21271A is from the containment wall near the fracture (as referenced in our November 11, 2009 report. It is our understanding that sample 21329 is from an area in the dome that was repaired several years ago. The purpose of our observations was to evaluate the similarities and/or differences in the coarse aggregate of the two samples to attempt to determine if the coarse aggregate used in sample 21329 is similar to coarse aggregate used in sample 21271A.

Additionally, as requested, parameters of the air void system were evaluated for sample 21271A in general accordance with the ASTM C 457-08 Standard Test Method for Microscopial Determination of Parameters of the Air-Void System In Hardened Concrete.

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In addition to the petrographic observations, the Mohs hardness of the coarse aggregates in samples 21271A and 21329 was evaluated using picks of known hardness.

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 of the coarse aggregate and discussion are as follows.

Aggregate

Sample 21271A

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, fosiliferous 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. The coarse aggregate had a moderate amount of void space. The limestone and fosiliferous limestone had a Mohs hardness of approximately 3.

On sample 21271, there were 4 coarse aggregate pieces on the cut surface of the core that retained moisture longer than other portions of the sample. A thin section was prepared from one of these pieces and this piece contained microcrystalline quartz and radial silica and exhibited localized evidence of alkali silica reaction

Sample 21329

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 and fosiliferous limestone. 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. The coarse aggregate had a moderate amount of void space. The limestone and fosiliferous limestone had a Moh's hardness of approximately 3.

DISCUSSION

Photographs comparing the features of the coarse aggregate in samples 21271A and 21329 are shown on pages 10 and 11.

The aggregates from both samples have the same general similarities.

- Both coarse aggregates have a Moh's hardness of about 3
- Both coarse aggregates are a fosiliferous limestone with similar fossils
- Both coarse aggregates have some particles with a moderate amount of void space
- Both fine aggregates are predominately quartz with a similar particle shape

A few limestone particles were observed in sample 21271A that contained microcrystalline quartz and radial silica (chert). Chert was not observed in sample 21329. Chert is found in association with some limestones in Florida. The material is formed by the replacement of calcium carbonate with silica that is carried in the ground water. The lack of chert in sample 21329 does not necessarily mean that the coarse

aggregate in sample 21329 is from a different source than the coarse aggregate in sample 21271A. In MACTEC's November 11, 2009 report, a petrographic analysis was performed on two samples (21271A and 21269A). It is our understanding samples 21271A and 21269A (both from the containment wall) are expected to be from the same source, however, chert was observed in sample 21271A and was not observed in sample 21269A.

It appears the coarse aggregate in both samples (21271A and 21329) could be from the same source or from the same general geologic deposit. It cannot be said with 100% certainty that both coarse aggregate samples came from the same source, however, we didn't see indications to suggest they are from different sources.

PARAMETERS OF THE AIR VOID SYSTEM

The parameters of the air void system were evaluated in general accordance with the ASTM C 457-08 Standard Test Method for Microscopial Determination of Parameters of the Air-Void System In Hardened Concrete. For this evaluation the modified point count method was utilized.

In our analysis, a total of 1,667 points were counted and each point was classified as a void, paste, coarse aggregate, or fine aggregate. Additionally, the number of voids that were traversed when going from point to point was recorded. The results are as follows:

Number Of Voids Intersected	327
Points In voids	52
Points In Paste	434
Points In Coarse Aggregate	683
Points In Fine Aggregate	498
Total Number of Points	1667

Following the calculations in ASTM C 457-08, the parameters of the air void system are as follows:

Air Content = 3.1%

Air content is the proportion of the total volume of the concrete that is air voids; expressed as a percentage by volume.

Void Frequency = 3.1 per inch

Void frequency is the voids per unit length of traverse; the number of air voids intercepted by a traverse line divided by the length of that line; the unit is a reciprocal length.

Paste Content = 26.0%

Paste content is the proportion of the total volume of the concrete that is hardened cement paste expressed as percentage by volume

Paste-Air Ratio = 8.34

Paste-Air ratio is the ratio of the volume of hardened cement paste to the volume of the air voids in the concrete

Average Chord Length = 0.002 inch

Average chord length is the average length of the chords formed by the transaction of the voids by the line of traverse; the unit is a length

Specific Surface = 2000 per inch

Specific surface is the surface area of the air voids divided by their volume, expressed in compatible units so that the unit of specific surface is a reciprocal length.

Spacing Factor = 0.0029 inch

Spacing factor is a parameter related to the maximum distance in the cement paste from the periphery of an air void, the unit is length

In addition to the above calculated values, by dividing the points in coarse aggregate by the points in coarse and fine aggregate (added together) we can calculate the volume of aggregate that is coarse aggregate. Based on this, the coarse aggregate fraction as 58% of the total aggregate volume similarly and the volume of aggregate that is fine aggregate as 42%. To equate these values to relative weight (for comparison to a mix design) the specific gravities of the aggregates would need to be known and additional calculations would need to be performed.

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

Sincerely,

MACTEC ENGINEERING AND CONSULTING, INC.

David C. Wilson
Senior Principal Professional

Ufuk Dilek Ph.D.
Senior Principal Professional

DCW/UD:pcc

Attachments: Photographs #1 - #4
Photomicrographs for Samples 21271A and 21329
Summary of Petrographic Observations for Cores 21271A and 21329

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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

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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	11-20-09
SAMPLE I.D.	21329
SAMPLE SIZE AND DESCRIPTION AS RECEIVED	Concrete core, approximately 1 ¾ inches in diameter, 2 pieces, each approximately 6 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 and fossiliferous limestone.
Alteration: - Degree - Products	Not observed
Coatings	Not observed
Rims	Not observed
Internal Cracking	Not observed
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:	Not Observed

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- Degree - Products	
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. Generally fairly evenly distributed
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	Not observed
Embedded Items - Shape - Size - Location - Type	Not observed
Alteration: - Degree & Type - Reaction Products - Location - Identification	Not observed
Nature and Condition of Surface Treatments	Not observed
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

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	with a hardened steel point
Porosity	Did not appear very porous.
Carbonation	The ½ inch of the exterior surface was 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
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