Characterization of Concrete Exposed to the H-Canyon Exhaust

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EXECUTIVE SUMMARY

This report provides a summary of concrete characterization results for the concrete cores collected from the north and south walls of the 221-H Section 3 Personnel Tunnel during 2016 and 2017. The goal was to (1) support the H-Area Canyon Exhaust (CAEX) Soil and Concrete Core Sampling and Analysis effort and (2) characterize the effects and depth of affected concrete exposed to the canyon exhaust environment (3) collect additional physical property data on 1950's concrete. The results of this characterization will be used to refine input parameters to the 2014 H-Area CAEX Tunnel Seismic Qualification Calculations.[1] The details of the testing and the results are reported herein.

The driver for the work is the observation that about 50 mm (2 inches) of wall thickness has been lost (exposed rebar) in the H-Canyon Cross-over Tunnel and the H-Canyon Exhaust Tunnel (CAEX) over more than 60 years of service. Figure ES-1 shows a view into the Cross-over Tunnel as viewed from a core hole in the wall separating the Personnel Tunnel from the Cross-over Tunnel, i.e., north wall. Approximately 2 inches of concrete wall loss has occurred exposing the first layer of the reinforcement bar structure. Thus, it was assumed there is a potential that the remaining concrete wall material may be altered as a function of depth from the surfaces exposed to the nitric acid vapor in the exhaust air stream.

Figure ES-1 – Cross-over tunnel viewed from core position N-3 looking west (May 2017 photograph).

The harvesting of the concrete cores and the core materials characterization was performed at the request of H-Canyon Engineering. This work provides supplemental information that can be applied to the CAEX structural qualification calculations and analysis of its structural capacity to meet design basis service demands. The specific application of the information in this report to the structural qualification analysis is outside the scope of this report.

Compressive Strength Properties of the 221-H Personnel Tunnel Walls (Bulk Concrete)

Mechanical and physical property testing of Section 3 of the 221-H Personnel Tunnel nonradioactive concrete core sections to provide concrete compressive strength, density, and porosity using standard ASTM methods was performed at the SRS Construction Materials Testing Laboratory (CMTL), and the results are reported herein. The complete set of test records are reproduced in Appendices E and G to this report.

The design thickness of both the north and south walls was 0.9 m (36 inches). Concrete coring operations were conducted in two phases. Phase 1, the full thickness of the south wall and about 2/3 of the thickness of north wall were cored from November to December 2016. Field measurements of the south wall thickness through the core holes showed the wall thickness of approximately 1.1 m (44 inches). A sheet pile panel abuts the exterior surface of the south wall. The increase in wall thickness from design thickness is an artifact from the corrugations in the sheet pile used in the 1950's facility construction.

Phase 2 coring operations were conducted from April to May 2017 to obtain core sections from the remaining wall thickness (about one third of the wall thickness). These cores were considered radioactive core sections because they had a surface exposed to the H-Canyon exhaust.

The north wall design thickness was 0.9 m (36 inches). The north wall thickness measured through the core holes was 0.86 m (33 ¾ inches) at the west end and 0.87 m (34 ¼ inches) east end of the corridor. The decrease in the wall thickness is presumed to be the result of more than 60 years of continuous exposure to nitric acid vapor in the exhaust air stream.

Statistical analysis of the compressive strength measurements made on the nonradioactive, "clean", core sections collected in 2017 from Section 3 of the 221-H Personnel Tunnel north and south walls are summarized below:

- Compressive strength measurements indicate that the north and south wall concretes are two separate materials populations;
- The mean compressive strength of the south wall concrete was calculated to be 26.4 MPa (3835 psi) based on 20 measurements corrected for coring damage and dimension (design strength for this concrete is 2500 psi); and
- The mean compressive strength of the north wall concrete is calculated to be 16.1 MPa (2336 psi) based on 29 measurements corrected for coring damage and dimension (design strength for this concrete is 2500 psi).

The Section 3 of the 221-H Personnel Tunnel north and south wall compressive strength data will be added to a larger database of concrete strength measurements for concrete placed at SRS during the early 1950s.

Petrographic analyses of two nonradioactive north and two nonradioactive south wall concrete cores were performed by the U.S. Army Core of Engineers in a separate task. The results were reviewed by the SRNL staff. Observations and interpretations of the petrographic evaluation of the nonradioactive, herein referred to as "clean" core sections are summarized below:

- The clean concrete in Section 3 of the 221-H Personnel Tunnel north and south walls is not expected to lose strength in the future due to normal aging.
- The clean concrete cores examined showed no indication of physical or chemical degradation.
- No evidence was found for alkali silica reaction (ASR) or any other degradation mechanism expressed as cracking from expansive reactions in the concrete.
- "Rims" on some of the coarse schist aggregates in the north wall cores were identified as clay which was present on the aggregate when the concrete was batched.
- Relatively high capillary porosity and microcracking were attributed to initial shrinkage. These microstructural features are consistent with a high water to cement (w:c) ratio of greater than 0.5 in the initial mixes.

- Clay coated aggregates and high capillary porosity in Section 3 of the 221-H Personnel Tunnel north wall concrete are most likely responsible for poor bonding between the paste and aggregates and the lower compressive strength of this wall compared to the south wall of the Tunnel.

Characterization of North Wall Core Sections Exposed to Canyon Exhaust

Five (5) radioactive concrete core sections, approximately 8" to 9" in length, were cut from the 221-H Personnel Tunnel north wall. A sixth core section was damaged during coring operations and was not fully characterized. These core sections included the surface of the Cross-over Tunnel wall exposed to the canyon exhaust, nitric acid vapor/air stream.

The suite of tests and measurements made on these radioactive core sections focused on identifying and understanding depth-dependent changes that occurred in the concrete and paste/matrix as a function of distance from the surface exposed to the canyon exhaust environment. The tests and measurements to provide depth-dependent material characterization are listed below:

Concrete

- Visual examination of the external surface features of the as-received cores: cracking, defects, color, macroscopic texture, uniform aggregate distribution, general integrity
- X-ray computed tomography of two cores (full length): internal porosity, macrotexture, uniformity, and identify differences or gradients in these properties as a function of distance from the exposed surface
- Alkalinity: colorimetric pH determination to evaluate carbonation sufficient alkalinity for rebar passivation
- Ultrasonic pulse velocity (UPV) measurements: nondestructive measurement of 54KHz ultrasonic wave travel time through concrete to identify differences in materials with the expectation of correlating measurements to physical and/or chemical differences.
- Petrographic examination using scanning electron microscopy coupled with energy dispersive spectroscopy (SEM/EDS) microstructure characterization and phase identification

Matrix/paste

- X-ray diffraction (XRD): mineralogy of the matrix phases
- Microhardness characterization: depth dependency of matrix hardness as an indicator of changes in competency
- Chemistry of matrix pore solution and soluble constituents in the concrete as an indication of the extent of nitric acid penetration into the wall: Pore solution chemistry was inferred from leaching of crushed matrix material and analysis of leachates for anions and cations.

The test records for the materials characterizations are contained in Appendices A through F to this report.

Observation of Physical Condition Changes

Loss of wall material exposed in the H-Canyon Cross-over Tunnel has occurred as indicated by the exposed aggregate and rebar documented in inspection photographs of the tunnel and protruding aggregates on the exposed surfaces of the cores. The exposed aggregates in the cores received by SRNL were securely attached to the matrix material as indicated through handling of the cores. There was no indication that the coring process dislodged exposed aggregates. The gravel aggregates and the quartz sand grains were securely anchored in the matrix and dislodging them required a hammer and chisel. The matrix was not friable, powdery, or obviously fractured.

The surfaces of all five concrete cores exposed to the canyon exhaust had a glossy appearance. The concrete cores (matrix not aggregate) were a darker color from the exposed surface to a depth. In four cores, the discolored region extended about 38 to 64 mm (1½ to 2 ½ inches) into the concrete. The discolored portion of Core N1-D extended about 89 mm (3½ inches) into the sample. The color transition was irregular because it followed aggregates but was distinct.

Observation of Chemical Alteration

Chemical alteration of the concrete with depth was observed. The changes were ascribed to nitric acid vapor and carbon dioxide/bicarbonate ion ingress into the concrete.

Nitric acid ingress: Chemical reactions between nitic acid and the alkaline phases in hydrated portland cement are expected to result in formation of soluble nitrate salts. Two cores, N4-D and N5-C, were evaluated for depth dependent soluble anions and cations concentrations. Leachates from pulverized matrix samples collected as a function of distance from the surface exposed to the canyon exhaust were collected and analyzed. High concentrations of nitrate ion (1000 to 3000 µg/mL) were contained in the leachates of material collected to a depth of about 50 mm (2 inches) from the surface. The charge balancing cation in these leachates was primarily Ca^{2+}.

Carbon dioxide/Carbonic acid ingress: Calcite, $CaCO_3$, was observed (XRD results) in the matrix. Calcite is the reaction product between atmospheric CO_2 in calcium phases in hydrated portland cement, $Ca(OH)_2$, C-S-H gel, and other calcium aluminate hydrate phases. For concrete exposed to moist air, this reaction typically occurs through intermediate acid compounds, such as bicarbonate ion, HCO_3^-.

The absence of portlandite, $Ca(OH)_2$, is also evidence of acid attack (nitric acid and/or carbonic acid). Portlandite was absent from the matrix phase assemblages of cores N3-D, N4-D, and N5-C between the surface, 76 mm (3 inches) for core N3-D, and 127 mm (5 inches) for cores N4-D and N5-C. Samples from cores N4-D and N5-C were not collected at 102 mm (4 inches). Calcite was detected in all five of these cores, N1 to N5, over the entire 7 to 9 inches of core evaluated.

The colorimetric phenolphthalein test for alkalinity confirmed XRD results that showed incomplete carbonation of all alkaline phases in the full length of the radioactive core sections. This test supports the conclusion that the alkalinity of the bulk concrete and the section exposed to the canyon exhaust provides rebar passivation (pH > 10.2). Completely carbonated matrix material was assumed to be removed from the surface by erosion due to the velocity (30 mph) of the canyon exhaust air stream.

Non-Destructive Evaluation of Compressive Strength: Direct measurements of compressive strength of the exposed surface region were not made using conventional testing (ASTM C39) because the strength was expected to be depth-dependent over distances much smaller than the minimum test specimen length required by 1½ inch aggregate. Therefore, a non-destructive technique, ultrasonic pulse velocity (UPV), was used to assess relative differences in material response as a function of distance from the exposed surface. UPV measurements were made at one-inch intervals.

A relationship was developed between the UPV and compressive strength results for the clean concrete core sections from the north and south walls. When the resulting equation was applied to the depth-dependent UPV results from the north wall radioactive core sections it did not result in a defensible correlation between these two properties. The compressive strength of the two inches of concrete nearest the exposed surfaces was predicted to be higher than the strength of the material between 2 and 8 inches from the exposed surface. However, this UPV-Compressive strength relationship for the radiologically contaminated core sections was judged to be invalid because the material near the surface was shown to be chemically and mineralogically altered compared to the bulk material. Evidence of the impact of chemical alteration on the UPV results was shown with a chart superimposing the UPV and chemical and mineralogical results. The nitrate-rich layers of these cores correspond to the regions with higher UPV velocities and roughly correspond to the 38 to 64 mm (1.5 to 2.5 inch) thick darker colored regions.

Microhardness measurements were made on the matrix in the core sections exposed to the canyon exhaust with the intent of evaluating relative differences in the matrix portion of the concrete as a function of distance from the exposed surface. Statistical analysis of the data showed that the average microhardness value of the depth-discrete matrix measurements was unchanged as a function of distance from the exposed surface.

Concluding Statement on Mechanical Properties of the Concrete Exposed to and Affected by the Canyon Exhaust

The composite conclusion from the radiologically contaminated core characterization is that two concurrent chemical alteration mechanisms of the hydrated portland cement matrix, selective nitric acid dissolution and secondary carbonate precipitation, coupled with wind erosion and scouring of damaged material are responsible for the physical features observed in the concrete exposed to the canyon exhaust. The exhaust air flow erosion conditions have not been investigated in detail.

The testing performed on the affected portions of the north wall cores do not conclusively demonstrate a change relative to the 2017 compressive strength of the north wall unaffected wall strength. That is, several depth-dependent material changes were observed, however there is no firm case to conclude that these material changes were manifested in an increase or a decrease from the bulk concrete compressive strength.

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LIST OF ABBREVIATIONS

ACI	American Concrete Institute
AD	Analytical Development
ASTM	American Society for Testing and Materials
CAEX	H-Canyon Exhaust Tunnel
CMTL	SRS Construction Materials Testing Laboratory
CSEM	Contained Scanning Electron Microscope
C-S-H	Calcium Silicate Hydrate
CT	Computed Tomography
DI	Deionized
DOT	Department of Transportation
EDS	Energy Dispersive Spectroscopy
ERDC	Engineering Research and Development Center
FE-SEM	Field Emission Scanning Electron Microscope
GS	General Services
HEU	High Enriched Uranium
LEU	Low Enriched Uranium
mph	Miles per hour
N	North (north wall)
PT	Personnel Tunnel
QA	Quality Assurance
S	South (south wall)
SDD	Silicon Drift Detector
SEM	Scanning Electron Microscopy
SRNS	Savannah River Nuclear Solutions, LLC
SRNL	Savannah River National Laboratory
SRS	Savannah River Site
UPV	Ultrasonic Pulse Velocity
USACE-ERDC	US Army Corps of Engineers-Engineering Research and Development Center, (Concrete and Materials Branch of the Geotechnical and Structures Laboratory, Vicksburg, MS)
VP	Variable Pressure
WDS	Wavelength Dispersive X-Ray Spectrometer
XCT	X-ray Computed Tomography
XRD	X-ray Diffraction

1.0 Introduction

This report provides a summary of concrete characterization results for the concrete cores collected from the north and south walls of the 221-H Personnel Tunnel during 2016 and 2017. The goal was to support H-Area Canyon Exhaust (CAEX) Soil and Concrete Core Sampling and Analysis and characterize the effects and depth of affected concrete exposed to the CAEX environment to refine and update input parameters to the 2014 H-Area CAEX Tunnel Seismic Qualification Calculations.[1] This task was requested by SRNS H-Canyon Engineering through a Technical Task Request.[2] The full scope of this concrete core characterization effort is provided in the H-Canyon Cross-Over Tunnel (HCAEX) Concrete Cores/Samples Characterization Task Technical and Quality Assurance Plan[3] and the SRNL H-Area Exhaust Tunnel (CAEX) Concrete Cores/Sample Characterization Plan.[4]

SRNL characterization activities were completed in two phases: Phase 1, non-radiological, “clean”, cores from the north and south walls of the Personnel Tunnel[5] and Phase 2, radiologically contaminated core sections recovered from the north wall of the Personnel Tunnel with surfaces exposed to the H-Canyon Cross-over Tunnel environment.

1.1 Objective

The objective of this task was to characterize up to eighteen (18) cores either 102 or 152 mm (4 or 6 inch) diameter collected from the 221-H Section 3 Personnel Tunnel, as outlined in the CAEX Tunnel Concrete Core Sampling Plan[1] and to provide updated concrete characterization data for the H-Canyon CAEX qualification calculations.[6] The concrete core characterization effort was designed to identify the depth of alteration caused by exposure to the exhaust tunnel environment.

The characterization activities included:

- Measure physical and mineralogical properties of the clean core sections to provide baseline information for the 60+ year old CAEX concrete which was not exposed to the canyon exhaust environment. These results support the preliminary assessment of residual strength of the altered concrete exposed to the canyon exhaust environment.

- Conducting testing to identify chemical, mineralogical and radiological profile as a function of distance from the exposed surface, and analyze results to provide a interpretation of the mechanisms responsible for the loss of wall thickness and alteration profiles.

Results from this characterization approach were not intended to address the projected serviceability of the CAEX tunnel.

1.2 Background

The primary mission of H-Canyon (221-H) is to dissolve, purify and blend-down surplus highly enriched uranium (HEU) and aluminum-clad foreign and domestic research reactor fuel to produce a low enriched uranium (LEU) solution suitable for conversion to commercial reactor fuel. H-Canyon was constructed in the early 1950s and began operations in 1955. The building is called a canyon because the footprint is long, high, and deep and includes two continuous rectangular subsurface structures that contains the process vessels. All work is remotely controlled, and employees are further protected from radiation by thick concrete walls.[7]

After more than 60 years of service with exposure to the high velocity (48 km/h, 30 mph) exhaust air containing nitric acid vapor and damp conditions, the concrete tunnel has experienced loss of wall thickness. The concrete condition has been monitored during inspections of the H-Canyon Exhaust Tunnel and Cross-over Tunnel conducted in 2003, 2009, 2011, 2014, and 2015, and 2017).[8] These inspections document that the loss of wall thickness has progressed to the point of exposing aggregate and steel reinforcement, i.e., about 50 to 65 mm (about 2 to 2.5 inches).[8] See Figure 1-1.

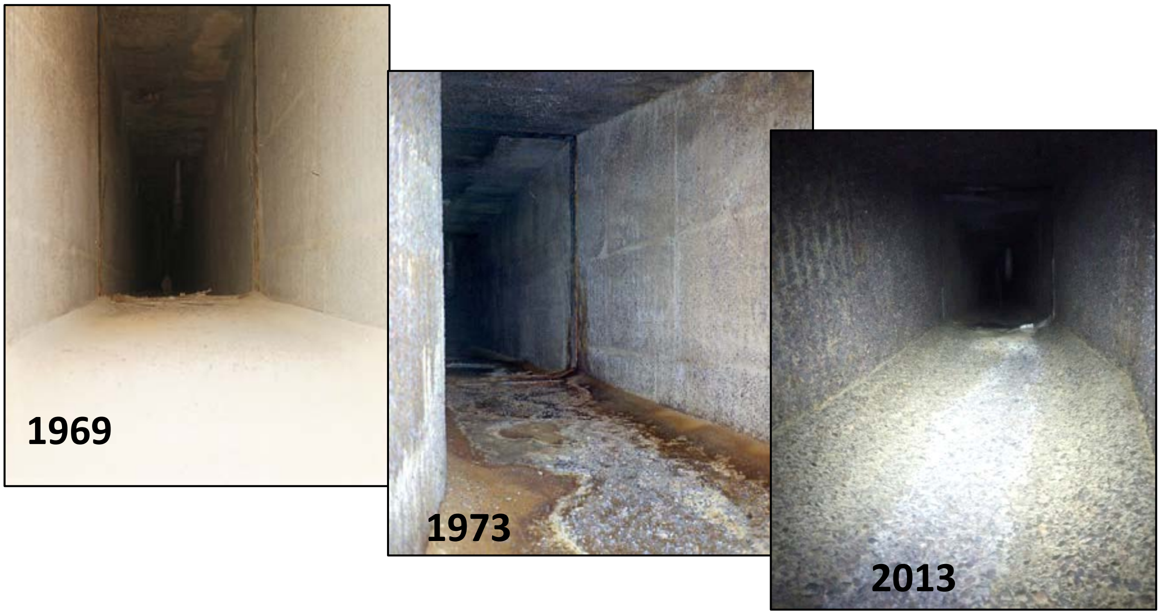


Figure 1.1. Pole Camera photographs at the Pitot Tube location in Section 4 of the H-Canyon Exhaust Tunnel.

Access to the CAEX is limited with respect to concrete core collection. Consequently, the north and south walls of the 221-H Section 3 Personnel Tunnel were selected for concrete core collection because of ease of access, lower worker safety risks, and minimal impact to the CAEX tunnel.[1] The south wall concrete was not in contact with canyon exhaust. Cores from the south wall were collected and characterized to provide information on 60+ year old SRS concrete. The north wall separates the Personnel Tunnel from the H-Canyon Cross-over Tunnel and is where the exhaust air streams from the warm and hot canyons are combined prior to entering the Exhaust Tunnel. The concrete in the Cross-over Tunnel and Exhaust Tunnel have experienced comparable thickness losses as is shown in Figure 1-2. Therefore, characterization of the Cross-over Tunnel served as a reasonable surrogate for evaluating the Exhaust Tunnel.

Figure 1.2. H Canyon Exhaust Tunnel Section 4 downstream of the current Recycle Vessel Vent and former Process Vessel Vent input streams (left) compared to the Cross-over Tunnel looking west through the N2 core hole (right)

The north and south walls of the 221-H Personnel Tunnel were constructed of reinforced concrete and are located below the 221-H base-mat. The north wall of the Personnel Tunnel separates the Personnel Tunnel and the Cross-over Tunnel which combines the process exhaust air from the warm and hot canyons and HB-Line into a single tunnel before exiting the H-Canyon structure to continue underground to the Sand Filter System. Schematic representations of the H-Canyon exhaust ventilation system and the locations of the cores that penetrated into the Cross-over Tunnel are shown in Figure 1.3 and Figure 1.4, respectively.

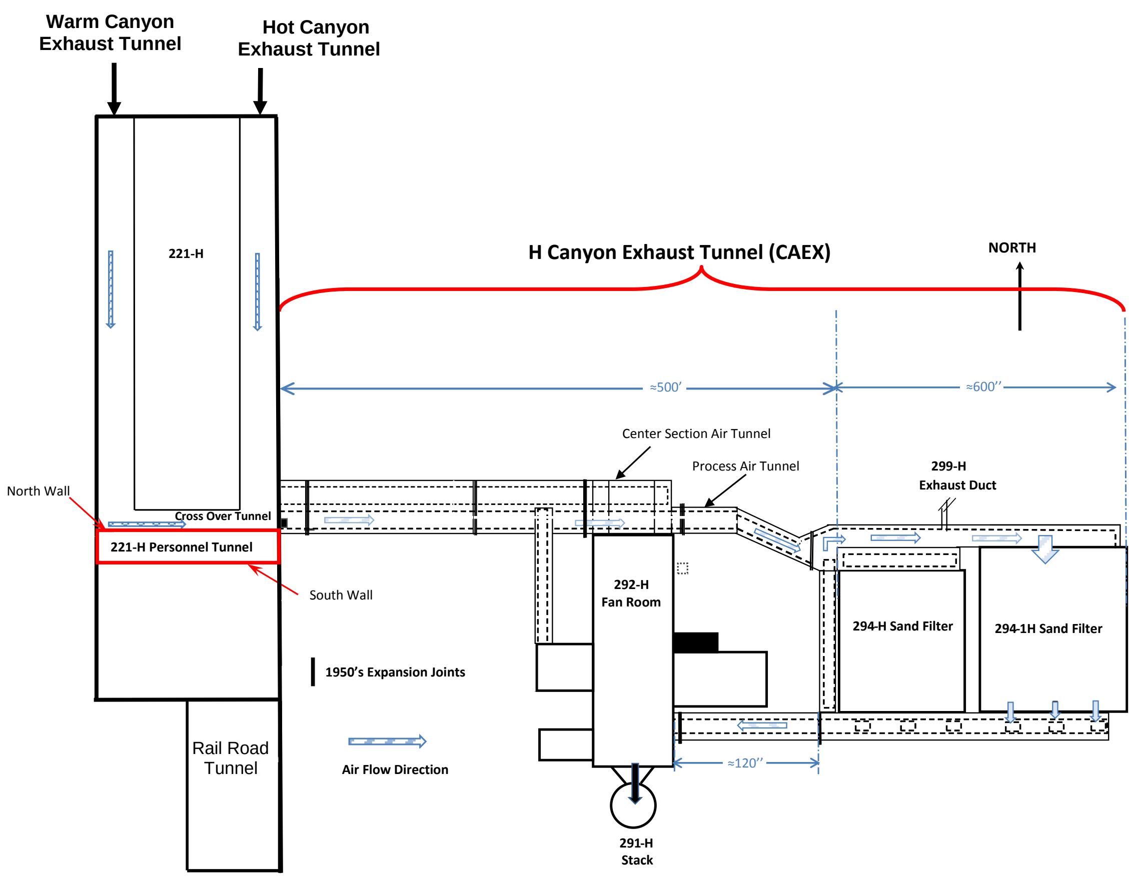


Figure 1.3. 221-H Canyon Exhaust Ventilation Diagram.

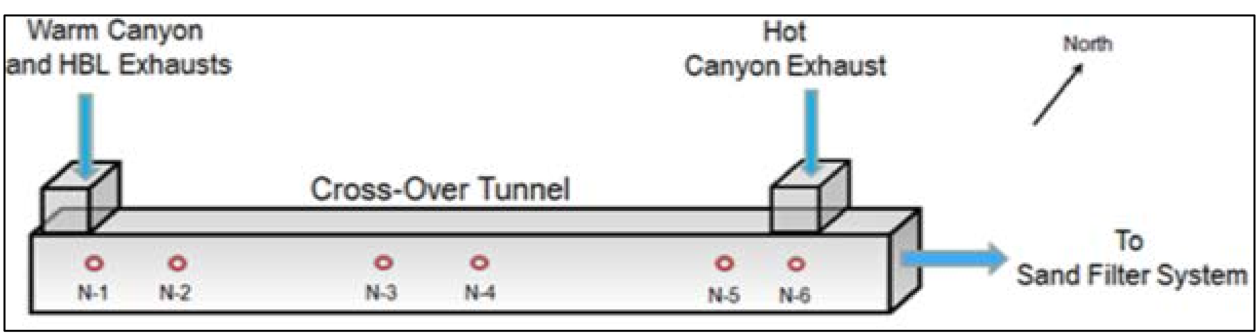


Figure 1.4. 221-H Section 3 Personnel Tunnel north wall illustrating the relative locations of the warm and hot canyon exhaust entry points into the Cross-over Tunnel relative to the radioactive core locations (Best Available Figure).

The south wall separates the Personnel Tunnel from the exterior soil environment. The north wall separates the CAEX from the Personnel Tunnel. The design thickness of both walls is 0.9 m (36 in.). The south wall was cored the entire thickness during December 2016 and January 2017. During the December 2016 and January 2017 coring activities, the north wall was initially cored to a depth of approximately 0.6 m (2 ft.). All concrete cores recovered from north and south walls during the December 2016 and January 2017 were designated clean samples based on radiological scans. During April and May 2017, the north wall core holes were extended the full thickness of the wall, i.e. into the radioactively contaminated Cross-over Tunnel. Photos of the 221-H Section 3 Personnel Tunnel before coring and with the core drill in place on the north wall are shown in Figure 1.5.

A sketch of the approximate core locations for 12 cores obtained through the north and south walls of the 221-H Personnel Tunnel is provided in Figure 1.6. Three additional cores up to approximately two feet long (non-radioactive) were taken at location N2 and three more were collected at location N6 (Figure 1.7). A six-inch core barrel was used to retrieve cores N2 and N5. All others were collected with a four-inch core barrel.

(a) Looking east: prior to coring

(b) Looking west: core drill set up for south wall non-radiologically contaminated sections.

Figure 1.5. 221-H Section 3 Personnel Tunnel.

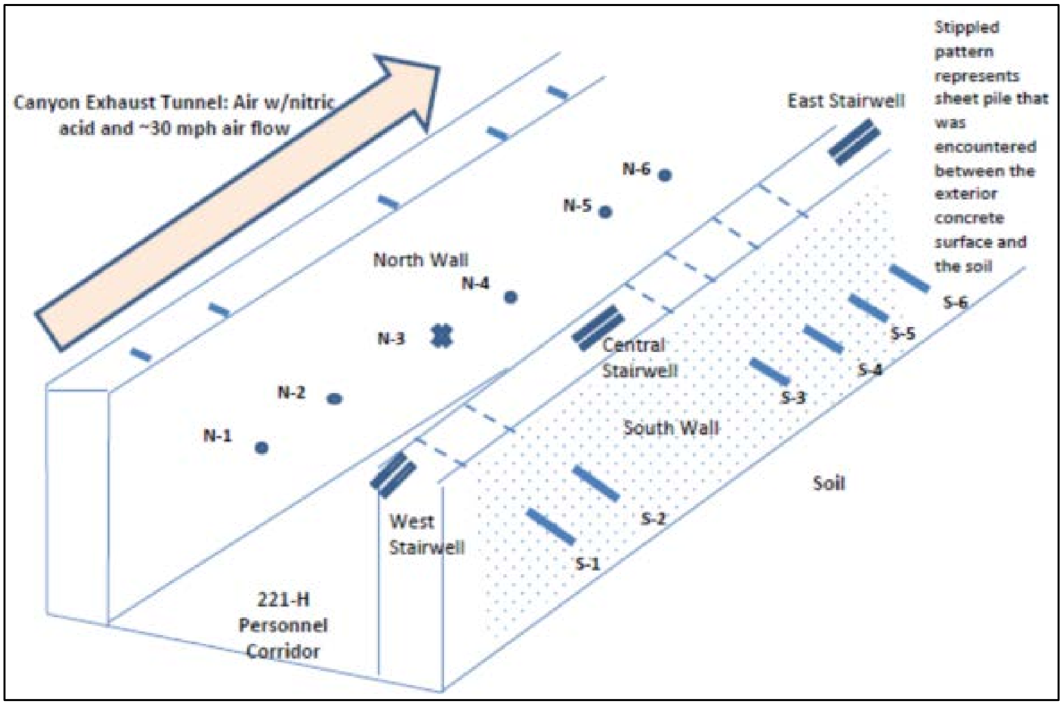


Figure 1.6. Concrete core locations in the north and south walls of the 221-H Section 3 Personnel Tunnel (Best Available Figure).

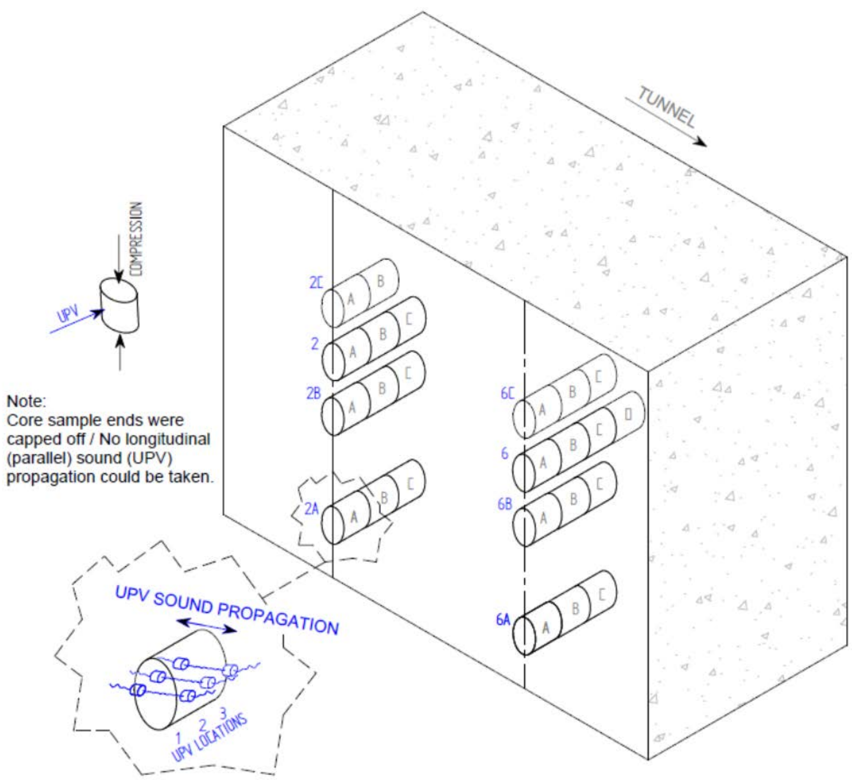


Figure 1.7. Additional core locations at positions N2 and N6 in the north wall of the 221-H Section 3 Personnel Tunnel. N2 and N6 cores were located between 2B and 2C and 6B and 6C, respectively.

1.3 Quality Assurance

The results presented in this technical report supersedes preliminary results presented in SRNL-L3100-2017-00010 and SRNL-L3200-2017-00087.

Requirements for performing reviews of technical reports and the extent of review are established in manual E7 2.60. SRNL documents the extent and type of review using the SRNL Technical Report Design Checklist contained in WSRC-IM-2002-00011, Rev. 2.

2.0 Core Handling and Characterization Methods

2.1 Core Identification and Handling

The clean concrete cores (non-radiologically contaminated) extracted from the south and north walls were sent to the Construction Materials Testing Laboratory (CMTL) in wooden boxes for physical and mechanical property measurements. They were cut into sections approximately 0.2 m (10 in.) long. Core sections were labeled using the scheme shown in Figure 2.1. Short pieces of core were used for porosity measurements and were labeled, BB (between B and C) and CC between C and D. Core identification numbers were assigned by H-Canyon Engineering. Cores from the north wall of the 221-H Personnel Tunnel were designated as 221H-PT-N#-C or D. The south wall cores were designated as 221H-PT-S#-D. For the purposes of this report the identification has been shortened to N#-C or D and S#-D.

Four clean cores sections, S2-D, S6-D, N1-B, and N2-B, and a piece of over core were sent to the USACE ERDC for additional evaluation.[14] The radiologically contaminated core sections from the 221-H Personnel Tunnel north wall were sent to SRNL for characterization.

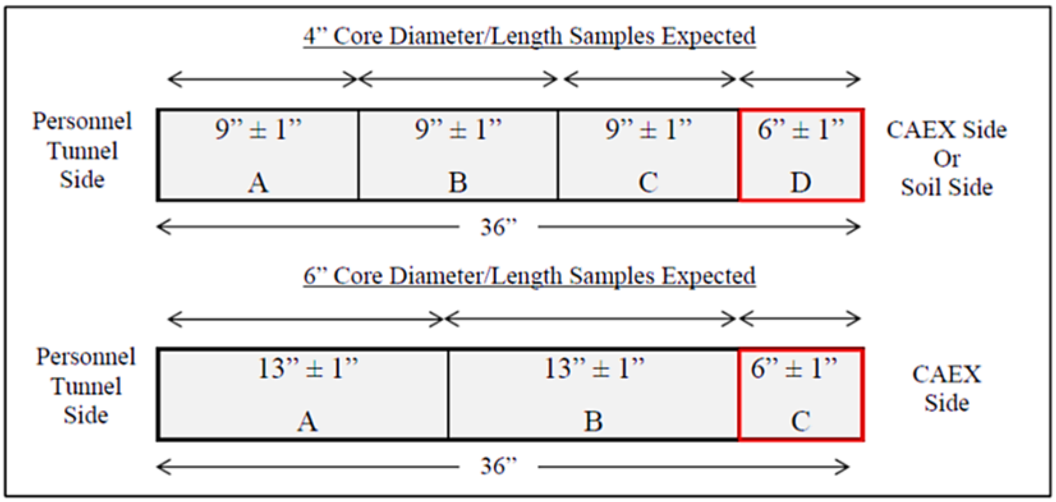


Figure 2.1. Core section labeling where red outlines indicate radiological sections.

2.2 Radiological Core Section Handling and Work Flow

The radiologically contaminated core sections were received at SRNL in DOT 7A containers. Cores N1-D, N2-C, N3-D, N4-D and N5-C were received intact. Due to problems encountered during coring (no cooling water), core N6-D was broken into many pieces. Consequently, SRNL characterization of N6-D was limited to radiological screening.

After unpackaging each core, a visual examination was performed to identify macroscopic features (cracks, color, irregularities) and non-destructive ultrasonic pulse velocity (UPV) measurements on the as received core sections. To assign appropriate radiological work control measures for additional characterization, two 20 g samples of matrix material were chipped out of each core and sent for radiological screening. One sample was collected near the exposed surface and the just below the transition in color which was about 2 inches (51 mm) from the surface. As the result of this initial sampling, Cores N1-D, N3-D and N4-D were broken (through core fracture) near the color discontinuity. Each core was repackaged for later characterization.

After radiological work control measures were identified and implemented, slabs were cut for microhardness and scanning electron microscopy (SEM) analysis. The mineralogical characterization required ground matrix material extracted from slabs as a function of distance from the surface. Figure 2-2 provides the scheme used to identify sub-sample locations from the radiologically contaminated core sections.

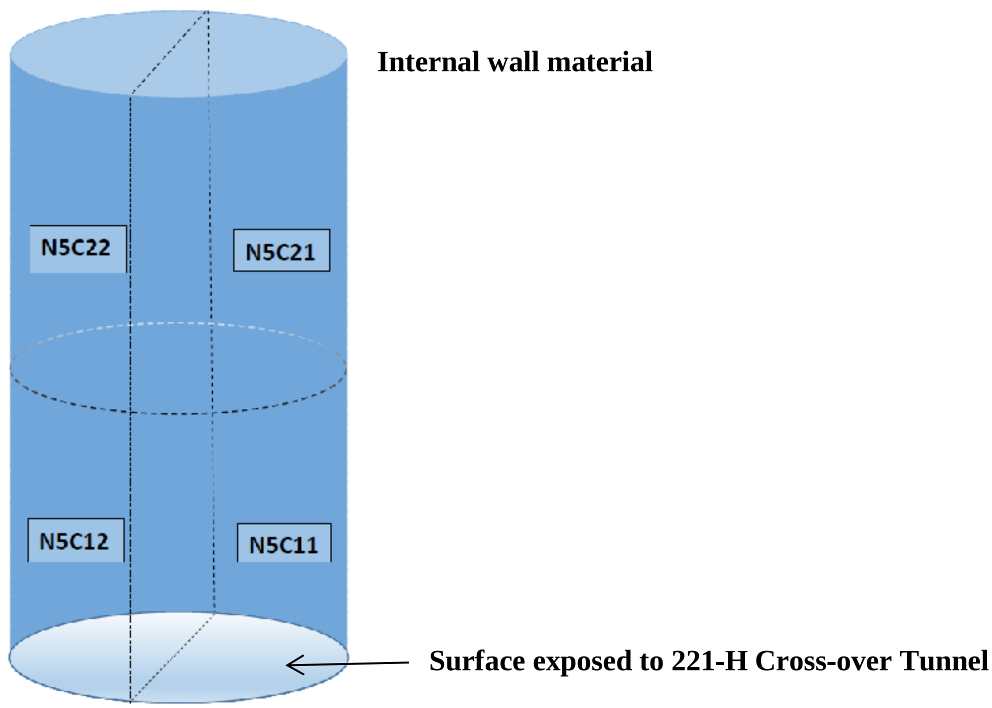


Figure 2.2. Labeling Scheme for Identifying Sub-sample Locations from Radiologically Contaminated Cores Sections.

2.3 Alkalinity Dye Test

The alkalinity test was performed in H-Area soon after each core was extracted (Figure 2.3). Alkalinity of the concrete was measured on core samples using an acid-base indicator solution. The solution of 1% phenolphthalein in isopropyl alcohol was applied to newly exposed cross-sectioned surfaces of each cores. If the area to which the dye was applied turned fuchsia, the pH of the concrete was greater than 10. The brighter the color, the higher the pH. If the dyed area was not stained fuchsia, the concrete pH was less than 8.2. Carbonation of concrete is commonly observed and results from reaction of hydrated Portland cement phases with atmospheric CO_2. The phenolphthalein dye test is therefore often referred to as the carbonation test.

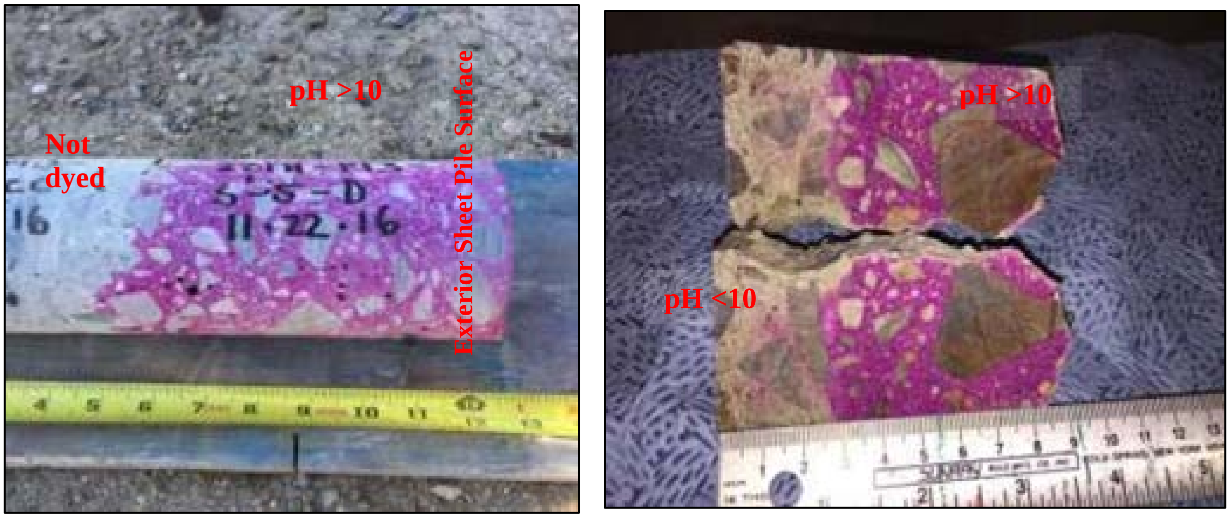


Figure 2.3. Illustration of alkalinity as a function of distance from a surface of core S-5-D (left) and core S-2-A (right).

2.4 <u>Visual examination</u>

Visual examination consisted of describing the as-received condition of the radiologically contaminated core sections with respect to core integrity, uniformity, unusual flaws, features on the surface exposed to the canyon exhaust, fine and coarse aggregate, cracking, and color. Each core was marked at 13 mm (½ inch) intervals along the long axis to identify the circumferential 0, 90, 180, 270° positions for UPV measurements. The exposed matrix surface was set as the zero point. Figure 2.4 is an example of a core section marked with distance from the exposed radioactive surface. Aggregates are shown protruding from the exposed surface. Note that the surface appeared "varnished" and the first few inches were a darker color than the rest of the core section.

Figure 2.4. Radiologically contaminated core section from the north wall of the 221-H Personnel Tunnel.

2.5 Ultrasonic Pulse Velocity

Ultrasonic pulse velocity (UPV) is a non-destructive method used to assess the concrete by measuring the velocity of a pulsed ultrasonic wave through concrete. A Pundit PL-200 unit with two 54 KHz bandwidth probes was used to measure transmission time and establish ultrasonic pulse velocity. Because ultrasound does not travel well in air, a gel couplant medium was applied to the probes to improve signal transmission across the core-probe interface. The system utilizes a calibration rod with a known transmission time to verify or correct transducer bandwidth reception from the unit processor and general system cohesion.

ASTM C597, Standard Method for Pulse Velocity Through Concrete[9] methodology was modified to evaluate each of the cores using one inch diameter probes (Figure 2.5). Given the size of the aggregate, 38 mm (1.5 inch), and the diameters of the cores, 10 and 15 cm (4 and 6 inches), the cores could not be trimmed to provide a flat surface. Hence the modification consisted of using the 1-inch diameter probes on the cylindrical surfaces. This modification (flat probe on a curved surface) was determined to not affect the results based measurements made on two clean north wall core sections (flat probes on flat surfaces, Appendix B Core N3-A Sections 1 and 2) and measurements made on south wall cores (flat probes on curved surfaces, Appendix F).

Figure 2.5. Ultrasonic Pulse Velocity (UPV) Sensor Layout.

UPV measurements were made on as-received cores clean and radioactive core sections with the probes oriented perpendicular to the core axis (Figure 2.5). UPV data were recorded a function of depth from the exposed surface. Measurements were taken in two transmission point configurations, with probes oriented around the circumference of the core at 0-180 degrees and 90-270 degrees. The transmission distance (core diameter) was measured at every measurement location along the core with calipers to 0.01 inches. Travel times were measured to $1x10^{-07}$ seconds.

Velocity is a measurement of distance / time. For a given distance a higher velocity results in a faster (lower) transmission time. All other factors being equal, a faster transmission time is indicative of a denser material. However, variables such as higher proportion of non-porous aggregate and moisture content can accelerate sound and give the appearance of higher density.

UPV measurements were made at a minimum of three locations on clean core sections at the Construction Materials Testing Laboratory (CMTL). Measurements on the radioactively contaminated cores from the north wall were made on 13 mm (½ inch) intervals for the first four inches and then 25 mm (1 inch) intervals for the remaining length of the as-received core. UPV measurements on the radioactively contaminated cores were conducted at SRNL in a radiological hood.

2.6 Compressive Strength, Porosity and Density

Standard concrete test methods were used for evaluating mechanical and physical properties of the non-radiologically contaminated north and south wall concrete cores.[10-12] ASTM C39, Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens,[10] identifies correction factors for sample length to diameters ratios other than the standard ratio of 2/1. The CMTL concrete technicians applied these corrections where needed. The American Concrete Institute Manual of Standard Practice, ACI 214-4R Chapter 8[12] identifies additional correction factors for core samples. These additional factors were applied where applicable by SRNL personnel (Equation 1).

$$f_c = F_{l/d} F_{dia} F_{mc} F_d f_{core} \qquad \textbf{Equation 1}$$

where: f_c = equivalent in-place strength

f_{core} = measured compressive strength

$F_{l/d}$ = correction factor for core length to diameter ratio

F_{dia} = correction factor for core diameter

F_{mc} = correction factor for moisture content other than that of the as received sample

F_d = correction factor for damage due to coring

A correction factor, f_d, of 1.06 was applied to all core samples. A correction factor F_{dia} of 0.98 applied to the 6 inch cores (Core N-2-C and N-5-C). The moisture content of all cores was as-received so no correction factor was applied for moisture.

Concrete density was determined by measuring the length, diameter, and mass of selected compressive strength samples prior to capping per ASTM C39/C39M[10]. Triplicate measurements of each parameter were measured and the average was calculated and reported by CMTL technicians.

ASTM C642, Standard Test Method for Density, Absorption, and Voids in Hardened Concrete, was used by the CMTL to determine the porosity of the non-radioactive core samples.[11] Porosity was reported as volume of permeable pore space.

2.7 Matrix Microhardness

Microhardness measurements were performed to ASTM C1327-15, Standard Test Method for Vickers Indentation Hardness of Advanced Ceramics.[13] The indenter used was a Vickers type indenter with an applied load which varied from 50 to 100 grams-force and a loading duration of 15 seconds. The indentations were measured in micrometers using a 40X objective (i.e., 400X magnification) microscope. The data are reported in Vickers hardness numbers (HV) which are calculated using Equation 2.

$$HV = 1854.4 \frac{Force}{d^2} \qquad \textbf{Equation 2}$$

where: *Force* = grams-force (gf)

d = mean diagonal length of the indentation (μm)

In some cases, the following exceptions in the ASTM C1327-15 method were noted: (1) specimens were ground and (2) specimens were polished to 1 μm instead of 0.1 μm.

Measurements were discarded and the data was not collected for the following conditions: (1) localized regions of the cement matrix to deviate from the standard orientation to the indenter axis (i.e., < 2° from perpendicular) due to differential polishing which resulted in the two diagonal lengths measuring more than 5% of the mean value; and (2) porosity, cracking and the presence of aggregate beneath the surface resulted in unacceptable indentations as defined in the standard.

2.8 Mineralogy by X-Ray Diffraction

Mineralogical evaluation is used to identify solid phases that make up the matrix and changes in these phases as a function of aging and environmental exposure. Both the USACE ERDC staff and the SRNL Analytical Development Section (ADS) researchers analyzed matrix samples extracted from the concrete cores. The USACE ERDC analyzed matrix from the clean, non-radioactive core section. Their sampling approach and x-ray diffraction (XRD) instrument are described their report.[14] SRNL collected and analyzed matrix sub-samples from the radioactive core sections (C or D) as a function of distance from the surface exposed in the Cross-over Tunnel to determine whether the matrix had been effected by the canyon exhaust.

At SRNL, small pieces of matrix material were chipped from locations identified along the axis of each radioactive concrete core section. The same measurement scheme was used for these samples as was used for the UPV and microhardness measurements, i.e., intact matrix on the exposed surface was set at zero and the cores were marked in half inch intervals the length of the rad cores. Sample/data gaps represent locations occupied by coarse aggregate in the slabs sampled. Portions of the small pieces were ground to approximately -200 mesh in the x-ray laboratory and mounted on substrates for XRD analyses.

XRD data were collected on a Bruker D8 X-ray Diffractometer by step scanning over the 2θ ranges of 5-70° with a step size of 0.02° and a dwell time of 1 second. Instrument parameters are listed in Table 2-1.

Table 2-1. Instrument 1A Parameters for Bruker D8 X-Ray Diffractometer.

Input Parameter	**Instrument Setting**
Radiation Source	CuKα X-ray
Source Power	45 kV, 40 mA
Wavelength	1.5405982 Å
Goniometer	Bruker D8
Divergence Slit (auto)	NA
Divergence Soller Slit	None
Divergence Antiscatter (fixed)	2mm
Specimen Rotation	No
Diffracted Beam Antiscatter(auto)	NA
Diffracted Beam Anitscatter(fixed)	Open
Diffracted Beam Soller Slit	2º
Receiving Slit	0.6mm
Secondary Monochromator	Curved pyrolytic graphite
Detector Scatter Slit	2mm
Detector	NaI Scintillation
2Θ Range	5º - 70º
Step Interval	0.02º (2θ)
Fixed Counting Time	1 s/step

Search-match identification of all the phases was performed with Jade 2010 software from Materials Data Inc. and the PDF4 database from the International Centre of Diffraction Data. Additional pattern analysis was performed using portland cement data base and other information from the literature.[21] Some phases identified by the JADE software were ruled out because their presence is highly unlikely in portland cement systems and in typical schist aggregate or quartz sand.

2.9 Scanning Electron Microscopy (SEM)

At SRNL, slabs were cut from the north wall core sections using Buehler Delta Orbital sectioning saw, equipped with a diamond abrasive blade and cooling water. The slabs were mounted in epoxy to facilitate grinding and polishing (starting with 600 grit silicon carbide grinding paper and finishing with 1µm diamond paste). The radioactively contaminated cores were cut into sub-samples about 51 x 89 mm (2 x 3.5 inches) so the sub-samples would fit into the SEM chamber (Figure 2.6). Aluminum foil boats were used as containers for the epoxy mounting and impregnation.

Figure 2.6. Epoxied and Polished Concrete Core Samples.

Two different scanning electron microscopes were used by SRNL ADS personnel to analyze the radioactive core sections. Carl Zeiss Microscopy LLC Sigma VP field emission scanning electron microscope (FESEM) with secondary electron, backscattered electron, and in lens secondary electron detectors was used to evaluate the microstructure of the radioactive sections of cores N-3-D, N-4-D, and N-5-C collected from the north wall of the H-Canyon Personnel Tunnel. The FESEM has an imaging capability up to 500,000X. This instrument has the variable pressure (VP) option which allows a variable pressure up to 133 Pascals of nitrogen gas to reduce or eliminate charging for uncoated samples. Energy dispersive spectroscopy (EDS) is performed using an Oxford Instruments X-Max 20 silicon drift detector to detect elements greater than atomic number 3 ($Z > 3$). EDS data and maps were analyzed using Oxford Instruments INCA 4.15 data analysis software. A conductive coating was not necessary because the variable pressure SEM setting was used and surface charging in the chamber atmosphere was minimal. Backscatter images and EDS data, including maps, were collected using an accelerating voltage of 30 kV for the electron beam.

The LEO S440 contained scanning electron microscope (CSEM), with an accelerating voltage up to 30 kV and capability of secondary electron imaging, backscatter electron imaging, and x-ray microanalysis was used to examine the radioactive sections of cores N1-D and N2-C. This instrument is contained in a radiological glovebox train. The CSEM includes an Oxford Instruments energy dispersive spectrometer (EDS) for detection of elements greater than atomic number 3 ($Z > 3$) and an Oxford Instruments wavelength dispersive x-ray spectrometer (WDS) for lower detection limits, resolution of EDS overlaps, and higher resolution x-ray collection. The Oxford Instruments INCA 4.15 software package allows for standardless semi-quantitative analysis, elemental mapping, and simultaneous EDS/WDS measurements. Samples were carbon coated to reduce charging. Secondary electron and backscatter images and EDS data, including maps, were taken using an accelerating voltage of 30 kV for the electron beam.

2.10 Soluble Ion Analysis

The reaction of nitric acid with the portland cement matrix phases was assumed to result in dissolution of calcium phases and formation of soluble nitrate salts/salt solution. Extraction of nitrate form sub-samples collected as a function of distance from the concrete surfaces exposed to the H-Canyon exhaust was performed on Cores N4-D and N5-C. Crushed matrix samples were leached in DI water. The sample to water ratio was 20x by weight. These slurries were tumbled continuously for approximately five days. At the end of the five days, the solids were separated from liquids through a 0.45 µm filter. The filtered aqueous samples were submitted to SRNL Analytical Development Section (ADS) for ion chromatography (anion) and inductively coupled plasma emission spectroscopy (cation) analyses.

2.11 Core X-ray Imaging

X-ray computed tomography (XCT) is a nondestructive technique for visualizing interior features within solid objects. Digital XCT was performed on half of core N3-D (N3D12, N3D22) and 1/4 of a core N4-D (N4D11, N4D21). The samples are shown in Figure 2.7. The SRNL XCT 420 System operated with a tungsten anode at 300 kV. Each core was contained in a Nalgene jar during the scanning as shown in Figure 2.8. Computed tomography images were compiled from the x-ray data.

Figure 2.7. Core samples N4-D (top) and N3-D (bottom) submitted for digital radiography and x-ray computed tomography.

Figure 2.8. Digital radiography equipment set up and core N4-D.

3.0 Results of Contaminated North Wall Core Sections

3.1 Radiological Screening of Contaminated North Wall Core Sections

The radiological screening results are provided in Table 3-1. These results were used to identify radiological work control measures needed to perform the required analyses.

Table 3-1. Radiological screening results for cores sections exposed to the H-Canyon Exhaust.

Core ID	Preliminary Radiological Results
N1-D	H-3 - 5.13E-04 µCi/g (exposed end) α - 507 dpm/g (internal) & 1860 dpm/g (exposed end) β - 3240 dpm/g (internal) & 8130 dpm/g (exposed end) γ - 944.04 dpm/g (internal) & 3233.85 dpm/g (exposed end) Gamma contributors include K-40, Cs-134, Cs-137, Eu-154, Pa-233, Np-237, Am-241
N2-C	H-3 - non-detect α - 135 dpm/g (internal) & 2220 dpm/g (exposed end) β - 1870 dpm/g (internal) & 5420 dpm/g (exposed end) γ - 382.64 dpm/g (internal) & 4495.47 dpm/g (exposed end) Gamma contributors include K-40, Cs-134, Cs-137, Eu-154, Bi-212, Bi-214, Pa-233, Np-237, Am-241
N3-D	H-3 - non-detect α - 124 dpm/g (internal) & 146 dpm/g (exposed end) β - 2210 dpm/g (internal) & 1630 dpm/g (exposed end) γ - 179.87 dpm/g (internal) & 1867.11 dpm/g (exposed end) Gamma contributors include K-40, Cs-134, Cs-137, Pb-212, Am-241
N4-D	H-3 - non-detect α - 148 dpm/g (internal) & 174 dpm/g (exposed end) β - 1280 dpm/g (internal) & 2260 dpm/g (exposed end) γ - 110.73 dpm/g (internal) & 1134.6 dpm/g (exposed end) Gamma contributors include K-40, Cs-137, Pb-212, Am-241
N5-C	H-3 - non- detect α - non-detect (internal) & 628 dpm/g (exposed end) β - 503 dpm/g (internal) & 1180 dpm/g (exposed end) γ - 186 dpm/g (internal) & 2548 dpm/g (exposed end) Gamma contributors include K-40, Cs-134, Cs-137, Eu-154, Pa-233, Np-237, Am-241
N6-D	H-3 – non-detect α - 430 dpm/g β - 11500 dpm/g γ - 408 dpm/g Gamma contributors include Cs-137

3.2 Visual Examination

Samples were initially measured, photographed, examined for color and other macroscopic features (Table 3-2 and Table 3-3). During the initial examination, three of the cores were broken at or near the color discontinuity visible on the outer surface of the cores as the result of sub-sample collection using a hammer and chisel.

Table 3-2. H-Canyon core sample receipt, initial observations, and planned characterization.

Sample ID	Date Received at SRNL	Initial Observations	Core Diameter		Approximate Length	
			(inches)	*(cm)*	(inches)	*(cm)*
N1-D	April 12, 2017 *Retrieved from wall 4/10/17*	Intact core with discoloration at exposed end	4	*10*	9	*23*
N2-C	April 12, 2017 *Retrieved from wall 4/10/17*	Intact core with discoloration at exposed end	6	*15*	9	*23*
N3-D	May 24, 2017 *Retrieved from wall 5/10/17*	Intact core with discoloration at exposed end	4	*10*	9	*23*
N4-D	May 24, 2017 *Retrieved from wall 5/10/17*	Intact core with discoloration at exposed end	4	*10*	9	*23*
N5-C	May 3, 2017 *Retrieved from wall 5/1/17*	Intact core with discoloration at exposed end	6	*15*	9	*23*
N6-D	May 3, 2017 *Retrieved from wall 5/1/17*	Many pieces Core was damaged during coring operations	4	*10*	unknown	

Table 3-3. Summary of visual characterization of 221-H-PT3 north wall core sections C or D.

<table>
<tr><th>Sample ID</th><th colspan="2">Description from Visual Examination*</th></tr>
<tr><td rowspan="2">N1-D</td><td colspan="2">Condition: 100 mm (4 inch) diameter core arrived intact
Aggregate: Schist coarse aggregate (multicolor (brown, gray and pink 10R 7/4), quartz sand fine aggregate.
Matrix: Variable color with sharp transition. Darker brown-gray color (10YR 6/2) extending from the exposed surface to about 63 to 89 mm (2½ to 3½ inches) into the wall. Beyond 89 mm (3½ inches) the matrix was lighter gray (2.5Y 7/1). The color transition line was irregular because it followed coarse aggregates.
Other: When collecting samples for radiological analyses, core broke at the color transition.
The concrete surface exposed in the Cross-over Tunnel appeared shiny or varnished (not friable or powdery). Coarse aggregates protruded from exposed surface about 19 to 25 mm (¾ to 1 inch) but were securely anchored in matrix.</td></tr>
<tr><td></td><td>
</td></tr>
<tr><td rowspan="2">N2-C</td><td colspan="2">Condition: 152 mm (6-inch) diameter core arrived intact. Irregular surfaces on the core and at the end of the core about 178 mm (7 inches) from the exposed surface were the result of coring technique.
Aggregate: Schist coarse aggregate (multicolor, brown, gray and pink 10R 7/4), quartz sand fine aggregate.
Matrix: Three color zones were observed as a function of distance from the exposed surface: darkest gray approximately 25 mm (1 inch) depth, lighter gray between 25 to 50 mm (1 to 2 inches).
Other: Exposed surface appeared shiny or varnished (not friable or powdery). Coarse aggregate protruded from the exposed surface about 10 to 20 mm (½ to ¾ inches) but were securely anchored in matrix.</td></tr>
<tr><td></td><td>
</td></tr>
</table>

* Colors were selected based on the Munsell Soil Color Charts.[15]

Table 3-3 (continued). Summary of visual characterization of 221-H-PT3 north wall core sections C or D.

<table>
<tr><th>Sample ID</th><th colspan="2">Description from Visual Examination*</th></tr>
<tr><td rowspan="2">N3-D</td><td colspan="2">Condition: 100 mm (4-inch) diameter core arrived intact.
Aggregate: Schist coarse aggregate (multicolor (brown, gray and pink 10R 7/4), quartz sand fine aggregate.
Matrix: Color change approximately 38 to 50 mm (1½ to 2 inches) from the exposed surface. Darker gray-yellow-brown color (10 YR 6/2) from exposed surface to a depth of approximately 38 to 50 mm into the wall. Remainder of the core was lighter gray and mottled (10YR 8/1 to 2.5Y 8/1 to 7/1).
Other: Exposed surface appeared shiny/varnished (not friable or powdery). Coarse aggregates protruded from the exposed surface 20 to 25 mm (¾ to 1 inch) but were securely anchored in matrix.</td></tr>
<tr><td></td><td>
</td></tr>
<tr><td rowspan="2">N4-D</td><td colspan="2">Condition: 100 mm (4-inch) diameter core arrived intact.
Aggregate: Schist coarse aggregate (multicolor (brown, gray and pink 10R 7/4), quartz sand fine aggregate.
Matrix: Color change approximately 38 to 50 mm (1½ to 2 inches) from exposed surface. Darker gray (10Y 7/1 or 10YR 6/1) transitioning to lighter gray (2.5Y 8/2 or 7/2). Transition is irregular.
Other: Exposed surface appears shiny/varnished (not friable or powdery). Coarse aggregates protruded from exposed surface up to about 19 to 25 mm (¾ to 1 inch) but were securely anchored in matrix.</td></tr>
<tr><td></td><td>
</td></tr>
</table>

* Colors were selected based on the Munsell Soil Color Charts.[15]

Table 3-3 (continued). Summary of visual characterization of 221-H-PT3 north wall core sections C or D.

Sample ID	Description from Visual Examination*
N5-C	**Condition:** 150 mm (6-inch) diameter core arrived intact. **Aggregate:** Schist coarse aggregate (multicolor (brown, gray and pink 10R 7/4), quartz sand fine aggregate. **Matrix**: Color change about 50 mm (2 inches) from exhaust tunnel surface. Darker gray (10YR 6/2 or 7/2) transitioning to lighter gray (2.5Y 8/2 or 7/2). Transition is irregular. **Other:** Uneven coring produced a pronounced lip on the surface of the core at approximately 178 mm (7 inches) from exposed surface. Exposed surface appears shiny/varnished (not friable or powdery). Coarse aggregates protruded from exposed surface up to about 19 to 25 mm (¾ to 1 inch) but were securely anchored in matrix.
	 
N6-D	**Condition:** 100 mm (4-inch) diameter core arrived in pieces. One piece of core was approximately 25 mm (1 inch) thick, but the location with respect to the exposed surface could not be determined. **Aggregate**: Schist coarse aggregate (multicolor (brown, gray and pink 10R 7/4), quartz sand fine aggregate **Matrix:** Color 10 YR 8/1 **Other:** Limited characterization was performed due to the condition of core upon arrival.
	

* Colors were selected based on the Munsell Soil Color Charts.[15]

3.3 Non-Destructive Matrix Characterization

SRNL performed the alkalinity dye test (phenolphthalein color indicator tests) at a field location in H-Area on cores N3-D and N4-D shortly after each core was removed from the wall. Discrete carbonated surface layers were not detected on core surfaces exposed to the CAEX environment nor the 221-H Section 3 Personnel Tunnel environment. Given the high porosity of the north and south wall concretes, the presence of partially carbonated regions was expected rather than a discrete carbonated surface layer that is more typical of higher strength, lower porosity concrete. Consequently, the chemical environment in the concrete is providing adequate alkalinity to maintain rebar passivation. Images of the alkalinity dye tests are provided in Appendix A.

The UPV results for the radiologically contaminated north wall cores exposed to the tunnel exhaust air are presented in Table 3-4. Measurements were made at 12.7 mm (1/2 inch) intervals along the long axes of the cores for the first 102 mm (4 inches) and then at 25 mm (1 inch) intervals for the remainder of the core section. The velocities ranged between 3337 m/s and 4724 m/s (10948 ft./s and 15500 ft./s). The data are presented in Appendix B. The highest velocities were measured within 76 mm (3 inches) of the core surfaces exposed to the canyon exhaust. The velocities decreased slightly as a function of increasing distance from the exposed surface. Statistical analysis of the UPV data is discussed in Section 6.2.

Table 3-4. UPV measurements as a function of circumference and distance from exposed surface.

	Distance from Exposed Surface (inches)											
(lnches)	**0.5**	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**	**5**	**6**	**7**	**8**
(mm)	*1.3*	*6.4*	*12.7*	*19.1*	*25.4*	*31.8*	*38.1*	*44.5*	*50.8*	*76.2*	*101.6*	*127.0*
Core Location	**UPV (feet/s)**											
N1-D 0-180º	14787	15317	13029	12757	13565	13029	13462	13593	14273	13684	13640	N/A
N1-D 90-270º	15171	15000	13013	12757	12851	13234	13463	13946	13405	12540	12188	N/A
N2-C 0-180º	14351	14264	12708	13915	13874	13673	14368	14368	14545	12317	12009	N/A
N2-C 90-270º	14178	14208	14051	13724	11427	13764	14093	13112	11454	10948	N/A	N/A
N3-D 0-180º	N/A	15423	15122	14286	12302	12016	11654	11742	12450	12109	12109	N/A
N3-D 90-270º	14486	14976	14692	13091	13537	12863	13305	12863	12971	N/A	N/A	N/A
N4-D 0-180º	14286	14352	13839	14091	15271	15500	13478	12157	12653	12863	N/A	N/A
N4-D 90-270º	15196	15347	14486	13478	12757	12500	12253	12500	12450	12450	N/A	N/A
N5-C 0-180º	14937	14937	14390	13111	13563	13761	13524	13333	13447	11859	11792	12412
N5-C 90-270º	14658	14347	14132	13296	12986	13111	13184	13148	12421	12896	12487	12487
Number of Samples	9	10	10	10	10	10	10	10	10	9	6	2
Mean	14817	14672	13946	13451	13345	13278	13213	13076	13007	12450	12407	12371
Standard Deviation	377	481	798	541	1024	942	797	801	932	760	662	53
Mean Absolute Difference to Mean	312	419	639	448	749	664	549	609	728	533	462	38
Mean Absolute Difference to Median	310	396	618	448	749	641	507	601	721	528	401	38

3.4 Matrix Microhardness

Core sections from radiologically contaminated cores N1-D through N5-C were sectioned and polished for microhardness measurements. Microhardness indentations were performed on select samples of the concrete core sections as a function of distance from the exposed surface. Samples were prepared by sectioning as discussed in Section 2.2. A grid was transcribed to the sample surface to enable the determination of the distance of each indent from the exposed surface (Figure 3.1). Core N1-D could not be measured due to the low surface quality of the polished specimens and large amounts matrix paste "pullout" which caused an uneven surface of the polished sections. Indentations of the cores N2-D through N5-C were measured periodically as a function of depth and the results are shown in Table 3-5 and plotted in Figure 3.2 through Figure 3.5. From these data, no trends in matrix hardness as a function of distance from the exposed surface were apparent. Some observations are listed below:

- Large scatter in measured hardness values.
- Slight increase in hardness was observed in cores N3-D and N5-C from 0 to 32 mm (1.25 inches) from the exposed surface.
- No increase in hardness was noted in cores N2-C and N4-D over the same region.
- The overall average of microhardness is 27.6 for the north wall cores, slightly higher than the sample from the south wall of the Personnel Tunnel (HV = 22.6).

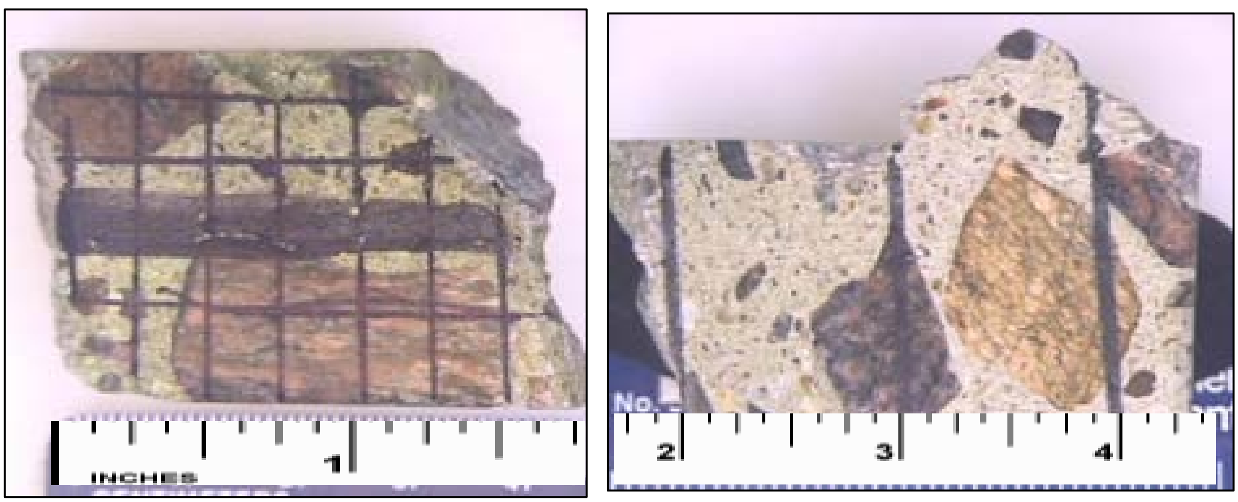


Figure 3.1. A grid transcribed to the sample surface of Core N5-C to enable the ability to track the distance from the exposed surface.

Table 3-5. Microhardness measurements for the north wall core sections exposed to exhaust tunnel environment.

	Distance from Exposed Surface												
(inches)	0.05	0.25	0.5	0.75	1	1.25	1.5	1.75	2	3	4	5	6
(mm)	*1.3*	*6.4*	*12.7*	*19.1*	*25.4*	*31.8*	*38.1*	*44.5*	*50.8*	*76.2*	*101.6*	*127.0*	*152.4*
Core	**Hardness (HV)**												
N2-C	--	24.1	23.3	21.4	16.5	22.2	31.6	--	37.7	21.1	18.4	--	--
	--	15.4	29.3	19.6	18.8	20.4	27.1	--	24.0	23.8	21.8	--	--
	--	31.1	54.4	24.7	29.0	16.3	17.9	--	25.4	22.4	25.6	--	--
	--	23.6	15.8	18.4	19.0	16.5	32.4	--	36.1	25.1	15.6	--	--
	--	26.5	20.1	14.1	17.3	23.9	26.4	--	34.3	39.6	19.9	--	--
	--	23.6	21.7	27.5	12.6	15.4	17.9	--	25.0	28.9	15.5	--	--
	--	--	18.1	18.1	16.1	15.2	14.5	--	24.1	32.5	11.9	--	--
	--	--	--	--	--	--	16.9	--	26.5	--	--	--	--
	--	--	--	--	--	--	--	--	24.5	--	--	--	--
N3-D	--	27.0	45.9	25.2	20.9	32.0	23.3	42.6	25.4	16.4	24.3	22.8	--
	--	35.7	34.8	32.2	43.2	54.1	30.3	15.1	31.9	20.2	28.3	16.3	--
	--	49.2	48.5	22.0	49.3	42.7	47.6	19.6	15.7	16.1	19.3	13.6	--
	--	25.0	34.9	25.6	21.0	38.6	--	36.2	13.0	14.3	25.2	14.0	--
	--	28.1	42.5	36.8	49.6	58.5	--	15.9	18.6	15.2	16.9	17.4	--
	--	22.3	17.4	19.8	44.5	25.1	--	17.2	22.0	--	30.6	14.8	--
	--	27.0	17.5	17.3	27.3	30.6	--	21.7	28.7	--	--	--	--
	--	--	--	27.0	47.9	--	--	23.8	--	--	--	--	--
	--	--	--	--	--	--	--	35.0	--	--	--	--	--
N4-D	--	--	45.0	29.3	71.1	47.9	22.5	44.2	29.9	20.7	30.3	16.1	42.2
	--	--	19.6	36.9	27.3	25.5	20.3	40.0	31.8	29.1	28.8	18.8	26.2
	--	--	21.2	30.4	39.3	21.9	34.3	45.1	--	46.7	42.0	29.6	18.8
	--	--	16.8	27.2	30.5	24.9	28.6	32.3	--	27.6	30.2	21.7	32.6
	--	--	44.1	26.1	30.6	26.4	--	29.2	--	21.1	26.4	19.3	30.6
	--	--	32.9	22.4	33.6	34.5	--	--	--	20.4	30.5	29.6	18.4
	--	--	38.6	23.8	17.8	23.3	--	--	--	15.9	45.8	--	21.5
N5-C	21.9	23.3	36.6	26.3	49.6	40.6	44.7	--	27.9	28.6	23.8	--	--
	17.6	48.8	36.3	37.8	41.5	60.7	30.7	--	22.7	20.4	31.8	--	--
	21.9	18.5	33.1	26.0	34.4	28.0	29.9	--	17.6	39.5	25.2	--	--
	18.4	11.3	27.2	18.2	23.8	48.1	20.5	--	20.4	34.7	18.7	--	--
	16.4	16.2	25.7	24.9	33.4	44.9	40.4	--	21.4	23.7	24.5	--	--
	24.4	25.1	14.4	29.6	40.6	57.7	23.2	--	29.8	26.2	15.6	--	--
	26.7	22.3	25.5	36.6	53.2	31.9	27.5	--	28.1	32.0	15.7	--	--
	22.4	23.1	25.4	--	47.3	--	--	--	--	--	--	--	--
	16.9	17.0	--	--	50.0	--	--	--	--	--	--	--	--
	22.1	28.4	--	--	31.7	--	--	--	--	--	--	--	--
	18.5	18.6	--	--	--	--	--	--	--	--	--	--	--
	--	23.1	--	--	--	--	--	--	--	--	--	--	--

-- Indicates no data collected. Core N1-C was not evaluated.

Table 3-5 (continued). Microhardness measurements for the north wall core sections exposed to exhaust tunnel environment.

	Distance from Exposed Surface												
(inches)	0.05	0.25	0.5	0.75	1	1.25	1.5	1.75	2	3	4	5	6
(mm)	*1.3*	*6.4*	*12.7*	*19.1*	*25.4*	*31.8*	*38.1*	*44.5*	*50.8*	*76.2*	*101.6*	*127.0*	*152.4*
	Hardness (HV)												
Number of Samples	11	25	29	29	32	28	22	14	25	26	27	12	7
Mean	20.7	25.4	29.9	25.7	34.0	33.1	27.7	29.9	25.7	25.5	24.5	19.5	27.2
Standard Deviation	3.3	8.8	11.2	6.3	14.0	14.0	8.8	11.0	6.2	8.3	8.0	5.5	8.6
Standard Error Mean	2.95	1.96	1.82	1.82	1.73	1.85	2.08	2.61	1.96	1.92	1.88	1.92	3.69
Lower 95 % Mean	14.9	21.5	26.3	22.1	30.6	29.5	23.6	24.7	21.9	21.7	20.8	13.9	19.9
Upper 95 % Mean	26.5	29.2	33.5	29.3	37.4	36.8	31.8	35.0	29.6	29.2	28.2	25.1	34.5

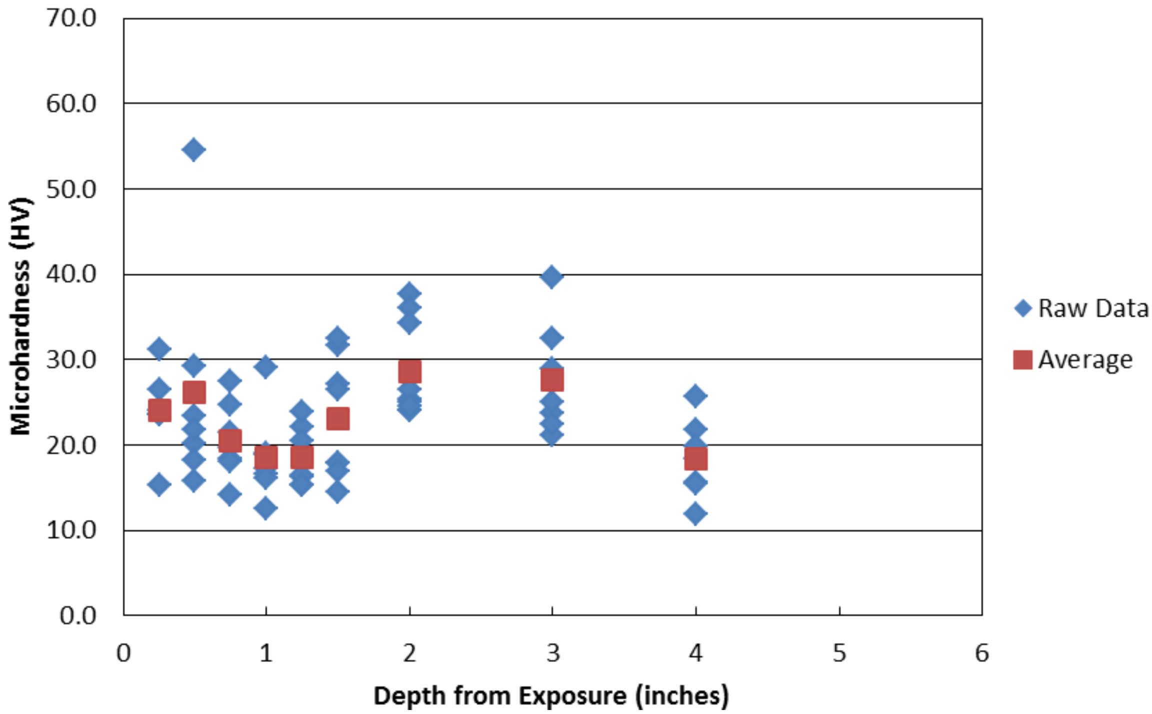


Figure 3.2. Microhardness of cement paste for core N2-C as a function of distance from surface exposed to canyon exhaust.

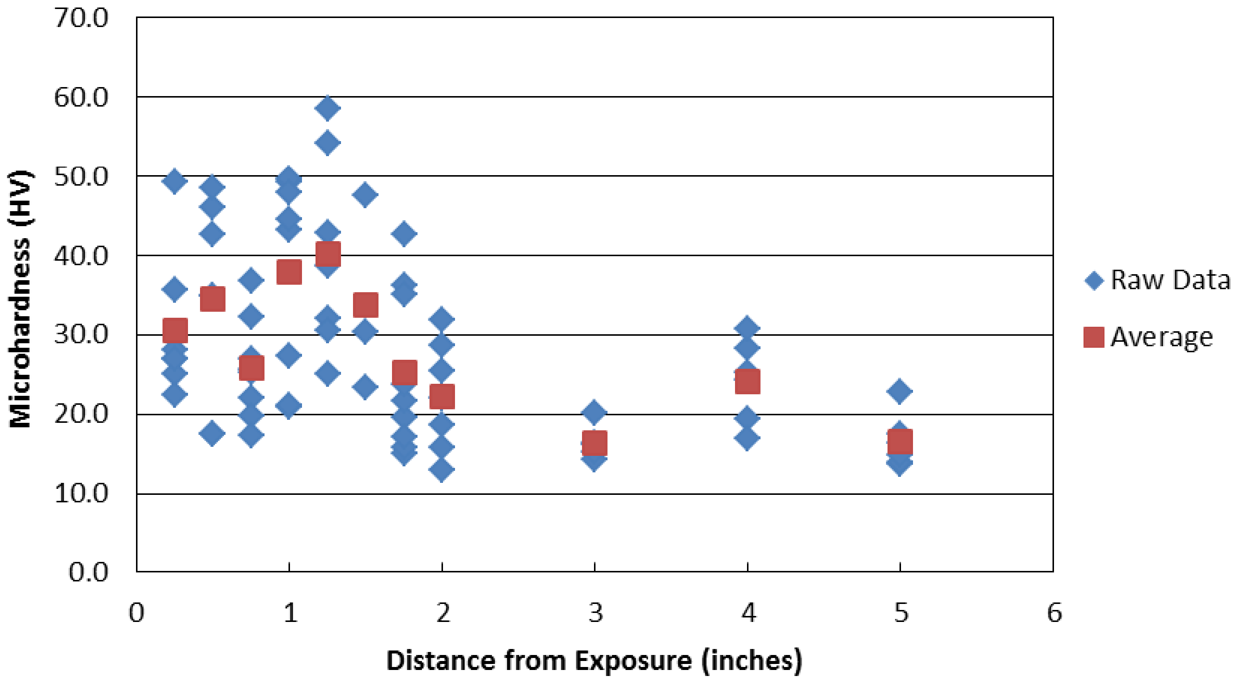


Figure 3.3. Microhardness of cement paste for core N3-D as a function of distance from surface exposed to canyon exhaust.

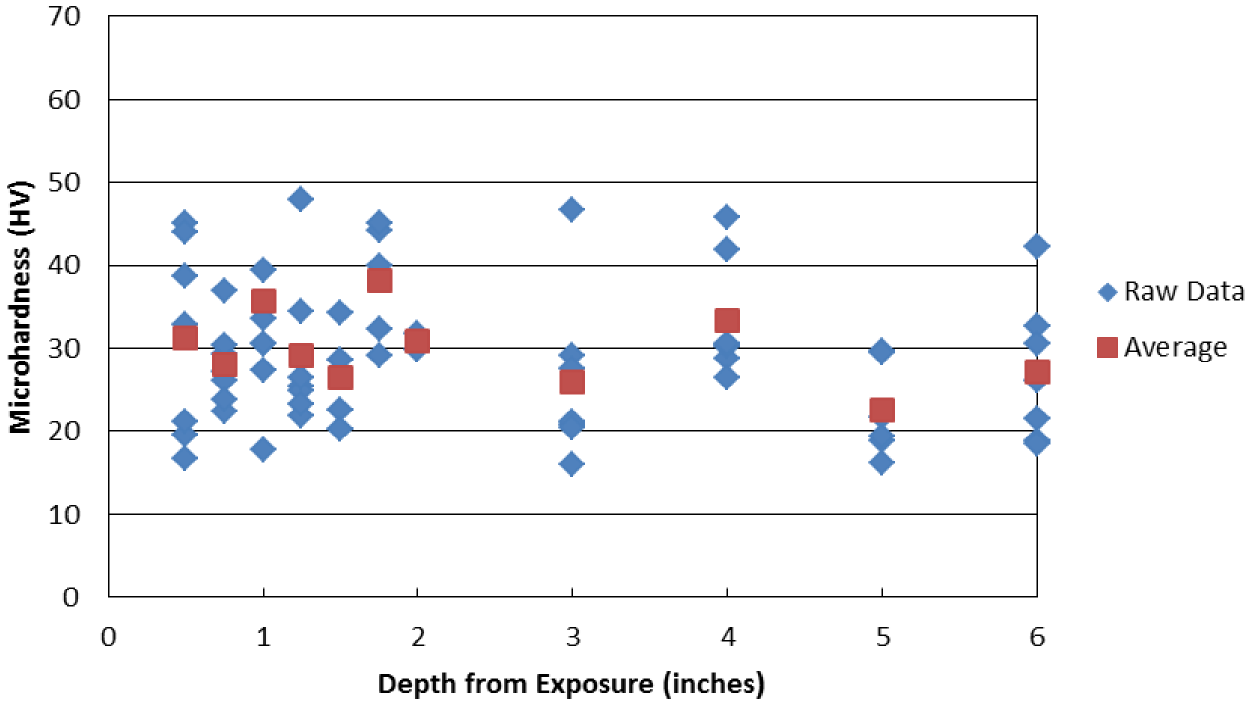


Figure 3.4. Microhardness of cement paste for core N-4-D as a function of distance from surface exposed to canyon exhaust. Note: Data point at 1 inch is not shown due to out of range.

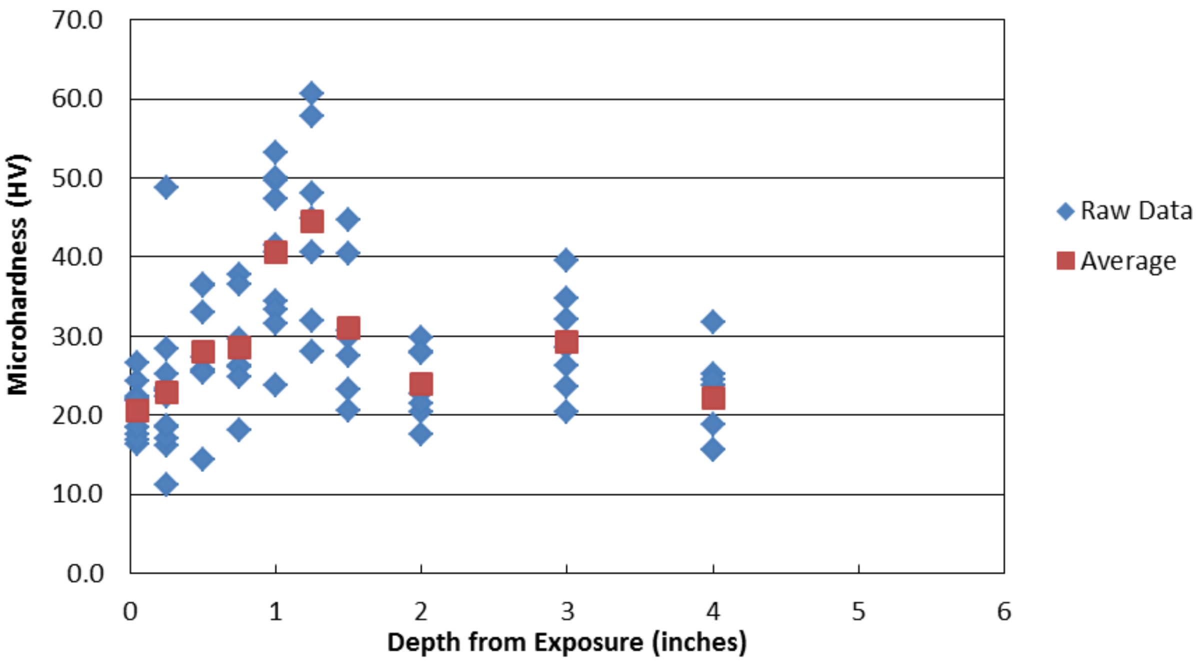


Figure 3.5. Microhardness of cement paste for core N5-C as a function of distance from surface exposed to canyon exhaust.

3.5 Matrix Mineralogy

Matrix samples were collected as a function of distance from the surface exposed to the canyon exhaust. Results for hydrated phases which bind the sand and gravel aggregates together are presented in Table 3-6. XRD powder patterns are provided in Appendix C.

Poorly ordered calcium silicate hydrate, commonly referred to as C-S-H gel, and crystalline phases typical of hydrated portland cement: hydrogarnet, ettringite, and a phase identified by the JADE software as hydrocalumite (which is a hydrated calcium aluminoferrite monosulfate hydrate) were identified in samples collected at the exposed surfaces and throughout the entire radioactive core sections.

Portlandite, $Ca(OH)_2$, was absent in patterns for sub-samples collected at the exposed surface and to a depth of approximately 76 mm (3 inches) from the exposed surface. Portlandite was detected in core N1-D at 152 mm (6 inches) (no samples between 76 and 152 mm), in core N2-C at 178 mm (7 inches) (no samples between 50 and 178 mm), in core N3-D between 76 and 102 mm (3 and 4 inches), in core N4-D at 152 mm, and in core N5-C at 127 mm (5 inches) (no samples between 76 and 127 mm).

Calcite, assumed to be an alteration product, was detected in most of the sub-samples from the surface to a depth of 229 mm (9 inches), i.e., the length of the radiologically contaminated core sections. The ubiquitous presence of calcite is suspicious but not unreasonable given the high porosity of the north wall concrete. However, another possible explanation may be that calcite and the calcium carbonate polymorphs aragonite and vaterite are impurities associated with the aggregates.

Phases other than hydrated matrix phases were detected in the x-ray powder patterns. These phases were grouped according to their origin and include:

Unreacted cement clinker phases which is commonly found in aged hydrated portland cement concrete.

- Larnite
- Brownmillerite

Anhydrous phases:

- Carbonated phases that were assumed to be formed by reaction of CO_2 and water[a] and the hydrated matrix phases.[b]
    - Three polymorphs of $CaCO_3$ were identified in the patterns (calcite, aragonite, and vaterite) in addition to a carbonated calcium aluminate hydrate.
- Quartz (sand fine aggregate).
- Quartz and albite (schist coarse aggregate).

Unexpected phases assumed to be from poorly washed aggregates.

- Illite and kaolilnite clay: assumed to be weathered schist phases, impurities, or fines associated with the aggregate.
- Other phases which were identified in numerous patterns were cancrinite, hydroxycancrinite, and chantalite. These phases do not form in hydrated portland cement. A review of the literature indicated that they are associated with weathered granite, schist, and other igneous and metamorphic rocks and are reported to be constituents of “red mud”.[16]
- Phases that could not be rationalized. These XRD peaks were reassigned or assumed to be misidentified.
    - Peaks identified as ye’elimite matched those for a calcium aluminate carbonate hydrate phase, $Ca_2Al(OH)_6[0.5CO_3{\cdot}2.5H_2O]$
    - Hilbrandite forms in hydrothermally cured portland cements
    - Dmitryivanovite has only been detected in meteorites.

[a] $CO_2 + H_2O = H_2CO_{3\ (\text{carbonic acid})} = HCO_3^-{}_{(\text{bicarbonate ion})} + H^+ = CO_3^{2-}{}_{(\text{carbonate ion})} + 2\ H_2O$

[b] Calcite is reported in “red mud” and therefore weathered schist or dirty aggregate cannot be ruled out as a source of some of the calcite. Aragonite was observed near the exposed core surface and vaterite is a metastable polymorph that had limited presence in the samples.

Table 3-6. Summary of concrete matrix phases identified by x-ray diffraction in the radioactive core sections from the north wall of the H-Canyon Personnel Tunnel (surface to 2.5 to 3 inches).

	Surface	0.25 to 0.5 inches	0.5 to 0.75inches	0.75 to 1 inch	1 to 1.5 inches	1.5 to 1.75 inches	2 inches	2.5 to 3 inches
N1-D	C-S-H* Hydrogarnet (Grossular) Ettringite Hydrocalumite (AFm) Calcite	No sample	C-S-H* Hydrogarnet (Grossular) Ettringite Hydrocalumite (AFm) Calcite		C-S-H* Hydrogarnet (Grossular) Ettringite Hydrocalumite (AFm) --	C-S-H* Hydrogarnet (Grossular) Ettringite Calcite		No sample
N2-C	C-S-H* Hydrogarnet (Grossular) Ettringite Hydrocalumite (AFm) Calcite	C-S-H * Hydrogarnet (Grossular) Ettringite Hydrocalumite (AFm) Calcite	C-S-H* Hydrogarnet (Grossular) Ettringite Hydrocalumite (AFm) Calcite		C-S-H* Hydrogarnet (Grossular) Ettringite Hydrocalumite (AFm) Calcite	C-S-H* Hydrogarnet (Grossular) Ettringite Calcite		No sample
N3-D	**Surface to 0.25 inches** C-S-H* Hydrogarnet (Grossular) Hydrocalumite (AFm) Calcite AFM phase $Ca_2Al(OH)_6[0.5CO_3 \cdot 2.5H_2O]$	No sample	C-S-H* Hydrogarnet (Grossular) Hydrocalumite (AFm) Calcite	No sample	C-S-H* Hydrogarnet (Grossular) Hydrocalumite (AFm) Calcite Vaterite	**1.5 to 2 inches** C-S-H * Hydrogarnet (Grossular) Hydrocalumite (AFm) Calcite	**2 to 2.5 inches** C-S-H * Hydrogarnet (Grossular) Ettringite Hydrocalumite (AFm) Portlandite Calcite Vaterite	C-S-H * Hydrogarnet (Grossular) Ettringite Calcite Vaterite
N4-D	C-S-H* Hydrogarnet (Grossular) Ettringite Hydrocalumite (AFm) Calcite Aragonite	C-S-H* Hydrogarnet (Grossular) Hydrocalumite (AFm) Calcite Aragonite	No sample	C-S-H* Hydrogarnet (Grossular) Ettringite Hydrocalumite (AFm) Calcite	C-S-H* Hydrogarnet (Grossular) Ettringite AFm (Calcium aluminate monosulfate) Calcite	No sample	C-S-H* Hydrogarnet (Grossular) Hydrocalumite (AFm) Calcite	C-S-H * Monosulfoaluminate Ettringite Calcite Vaterite
N5-C	C-S-H* Hydrogarnet (Grossular) Hydrocalumite (AFm) Calcite	C-S-H* Hydrogarnet (Grossular) Hydrocalumite (AFm) Calcite	C-S-H* Hydrogarnet (Grossular) Ettringite Hydrocalumite (AFm) Calcite	C-S-H* Hydrogarnet (Grossular) Ettringite Hydrocalumite (AFm) Calcite	C-S-H* Hydrogarnet (Grossular) Ettringite Hydrocalumite (AFm) Calcite	C-S-H* Hydrogarnet (Grossular) Ettringite Hydrocalumite (AFm) ---	C-S-H* Hydrogarnet (Grossular) Ettringite Hydrocalumite (AFm) ---	C-S-H * Hydrogarnet (Grossular) AFm phase $(Ca_2Al(OH)_6[0.5CO_3 \cdot 2.5H_2O])$

*C-S-H, calcium silicate hydrate, is the primary binding phase in the matrix and has a disordered crystal structure (short range order) and is indicated on x-ray diffraction patterns between approximately 20° and 40° 2-Theta as a very broad peak (rise in background). Red text indicates alteration and --- indicates alteration product not detected

Table 3-6 (continued). Summary of concrete matrix phases identified by x-ray diffraction in the radioactive core sections from the north wall of the H-Canyon Personnel Tunnel (4 inches to 9 inches).

	4 inches	5 inches	6 inches	7 inches	8 inch	9 inches
N1-D	No sample	No sample	C-S-H* Hydrogarnet (Grossular) Ettringite Portlandite Calcite	No sample	No sample	No sample
N2-C	No sample	No sample	No sample	C-S-H* Hydrogarnet (Grossular) Ettringite Portlandite Calcite	No sample	No sample
N3-D	**3 to 4 inches** C-S-H * Hydrogarnet (Grossular) Ettringite AFm (Calcium aluminate monosulfate) Portlandite Gypsum Calcite Vaterite	C-S-H* Hydrogarnet (Grossular) Portlandite Calcite Vaterite	C-S-H* Hydrogarnet (Grossular) Portlandite Calcite Vaterite	C-S-H* Hydrogarnet (Grossular) AFm phase (Ca2Al(OH)6[0.5CO3·2.5H2O]) Calcite Vaterite	No sample	No sample
N4-D	No sample	C-S-H* Hydrogarnet (Grossular) Calcite	C-S-H* Hydrogarnet (Grossular) Portlandinte Calcite	C-S-H* Hydrogarnet (Grossular) Portlandinte Calcite Vaterite	No sample	No sample
N5-C	No sample	C-S-H* Hydrogarnet (Grossular) Ettringite AFm (Calcium aluminate monosulfate) Portlandite Calcite	C-S-H* Hydrogarnet (Grossular) Ettringite AFm (Calcium aluminate monosulfate) Portlandite Calcite	C-S-H* Hydrogarnet (Grossular) Ettringite AFm (Calcium aluminate monosulfate) Portlandite Calcite	C-S-H* Hydrogarnet (Grossular) Ettringite AFm (Calcium aluminate monosulfate) Portlandite Calcite	C-S-H* Hydrogarnet (Grossular) Ettringite AFm (Calcium aluminate monosulfate) Portlandite Calcite

*C-S-H, calcium silicate hydrate, is the primary binding phase in the matrix and has a disordered crystal structure (short range order) and is indicated on x-ray diffraction patterns between approximately 20° and 40° 2-Theta as a very broad peak (rise in background). Red text indicates alteration and --- indicates alteration product not detected

Table 3-7. Mineral names and chemical formulas for all phases identified in diffraction patterns of radioactive core sections from the north wall of the H-Canyon Personnel Tunnel.

JCPDF Pattern Number	Phase Name	Composition	Cement Notation
Hydrated Portland Cement Phases			
Broad peak between about 20° and 40° 2-Theta	Poorly crystalline calcium silicate hydrate	Calcium silicate hydrate	C-S-H
00-004-0733	Portlandite	$Ca(OH)_2$	CH
00-045-1447	Grossular (hydrogarnet)	$Ca_3Al_2(SiO_4)1.25\cdot (OH)_7$	C_3AH_6
00-041-1451	Ettringite	$Ca_6Al_2(SO_4)_3(OH)_{12}\cdot 26H_2O$	$C_6A\boldsymbol{S}H_{32}$ (AFt Phase)
00-045-0158	Calcium aluminate monosulfate hydrate	$Ca_4Al_2SO_{10}\cdot 12H_2O$	$C_4A\boldsymbol{S}H_{12}$
00-042-0558 Highway Research Boar SP 12700-045-0158	Hydrocalumite identified with x-ray diffraction phase analysis software. More likely solid solution between tetracalcium aluminate hydrate and tetracalcium aluminate monosulfate hydrate	$Ca_2AlOH)_6Cl\cdot 2H_2O$ $Ca_2Al(OH)_6[OH\cdot 2.5$ to 3 and $H_2O]$ $Ca_2Al(OH)_6[0.5(SO_4)\cdot 3H_2O]$	C_4AH_{13} and $C_4A\boldsymbol{S}H_{12}$ (AFm phases)
Residual Unhydrated Portland Cement Phases			
04-008-1786	Larnite	Ca_2SiO_4	C_2S
00-030-0226	Brownmillerite	$Ca_2(Al,Fe^{+3})_2O_5$	$C_2(A,F)$
Alteration Phases (all carbonated)			
00-005-0586	Calcite	$CaCO_3$	$C\boldsymbol{C}$
00-060-0483	Vaterite	$CaCO_3$	$C\boldsymbol{C}$
00-005-0453	Aragonite	$CaCO_3$	$C\boldsymbol{C}$
Highway Research Boar SP 127	AFm phase (carbonated)	$Ca_2Al(OH)_6[0.5CO_3\cdot 2.5H_2O]$	$C_4A\boldsymbol{C}H_{11}$
Aggregate Phases and Clays			
00-046-1045	Quartz	SiO2	
00-041-1480	Albite	$(Na,Ca)Al(Si,Al)_3O_8$	
00-026-0911	Illite	$(K,HO_3)Al_2Si_3AlO\cdot 10[(OH)_2(H_2O)]$	
00-058-2001	Kaolinite	$Al_2Si_2O_6(OH)_4$	
Phases reported to be found in "red mud"[16]			
00-045-1457	Hydroxycancrinite	$Na_8Al_6Si_6O_{24}(OH)_2\cdot 2H_2O$	
00-048-1862	Cancrinite	$Na_6CaAl_6Si_6(CO_3)O_{24}\cdot 2H_2O$	
00-029-1410	Chantalite	CaAl2SiO4(OH)4	
Phases with questionable identification			
00-061-0248	Dmitryivanovite found in meteorite	$CaAl_2O_4$	
00-033-0256	Ye'elimite	$Ca_2Al(OH)_6[0.5CO_3\cdot 2.5H_2O]$	Found in hydrated v. high aluminate cement

3.6 Matrix Leachate Analyses

Matrix samples of two radioactive cores, N4-D and N5-C, were collected as a function of distance from the surface exposed to the canyon exhaust. These samples were crushed and leached in DI water as described in Section 2.10. The matrix to leachate mass was 1:20 for all samples. The leachates were analyzed for anions, specifically nitrate, NO_3^-, and selected elements, specifically Ca, K, and Na. Nitrate salts are the reaction products between nitric acid and alkaline phases, such as those present in the portland cement matrix. The results are tabulated in Table 3-8 and plotted in Figure 3.6. Nitrate concentrations in the leachate were above the uncertainty value of 10 µg/mL to a depth of 5 inches in core N4-D and a depth of 9 inches in core N5-C. For both cores, the amount of nitrate extracted from the matrix decreased considerably between about 51 and 102 mm, respectively (2 and 4 inches) from the surface.

Table 3-8. Nitrate concentration in matrix leachates as a function of distance from the exposed surface.*

N4-D Distance from exposed surface	**(inches)**	0.125	0.375	0.875	1.25	1.625	2.25	5	6	7
	(mm)	*3.2*	*9.5*	*22.2*	*31.7*	*41.3*	*57.2*	*127*	*152*	*178*
Nitrate in Leachate	**(µg/mL)**	2550	2510	1820	1860	280	400	22.5	10	10
N5-C Distance from exposed surface	**(inches)**	0.125	0.375	0.625	0.875	1.25	1.625	2	4	9
	(mm)	*3.2*	*9.5*	*15.9*	*22.2*	*31.7*	*41.3*	*50.8*	*101.6*	*228.6*
Nitrate in Leachate	**(µg/mL)**	1800	2380	3660	3080	3800	2190	980	149	22.7

* uncertainty in nitrate values is 10 µg/mL

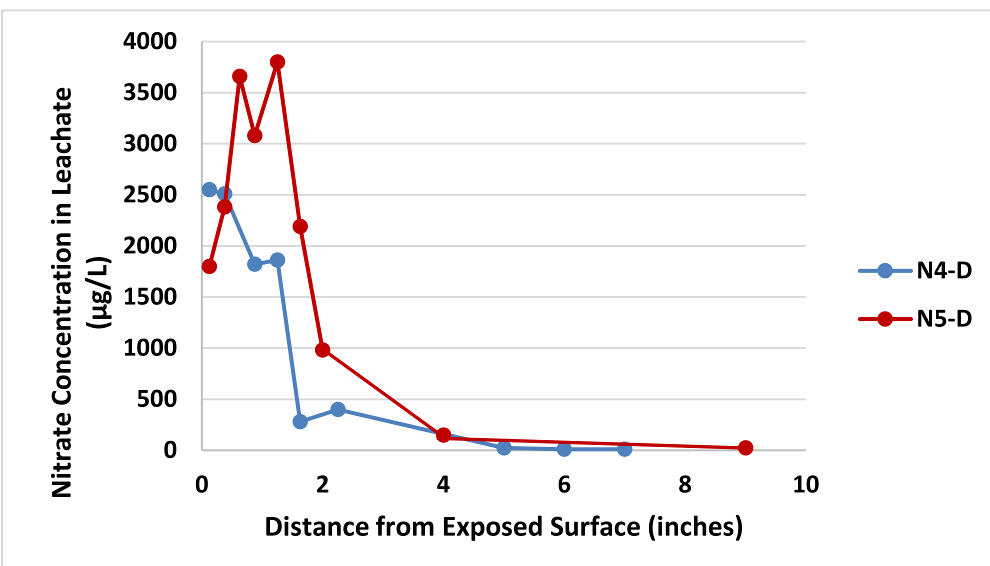


Figure 3.6. Nitrate concentration in matrix leachates as a function of distance from surface exposed to the H-Canyon exhaust.

Ca, K, and Na concentrations in the leachates are tabulated in Table 3-9. The objective of analyzing and reporting these constituents was to evaluate the potential for alkali silica reaction by measuring the soluble alkalis involved in formation of ASR expansive gel, K and Na. Ca in the pore solution and leachate is available to form non-expansive C-S-H gel in the presence of reactive silica.

Table 3-9. Selected cation concentrations in matrix leachates as a function of distance from the exposed surface.

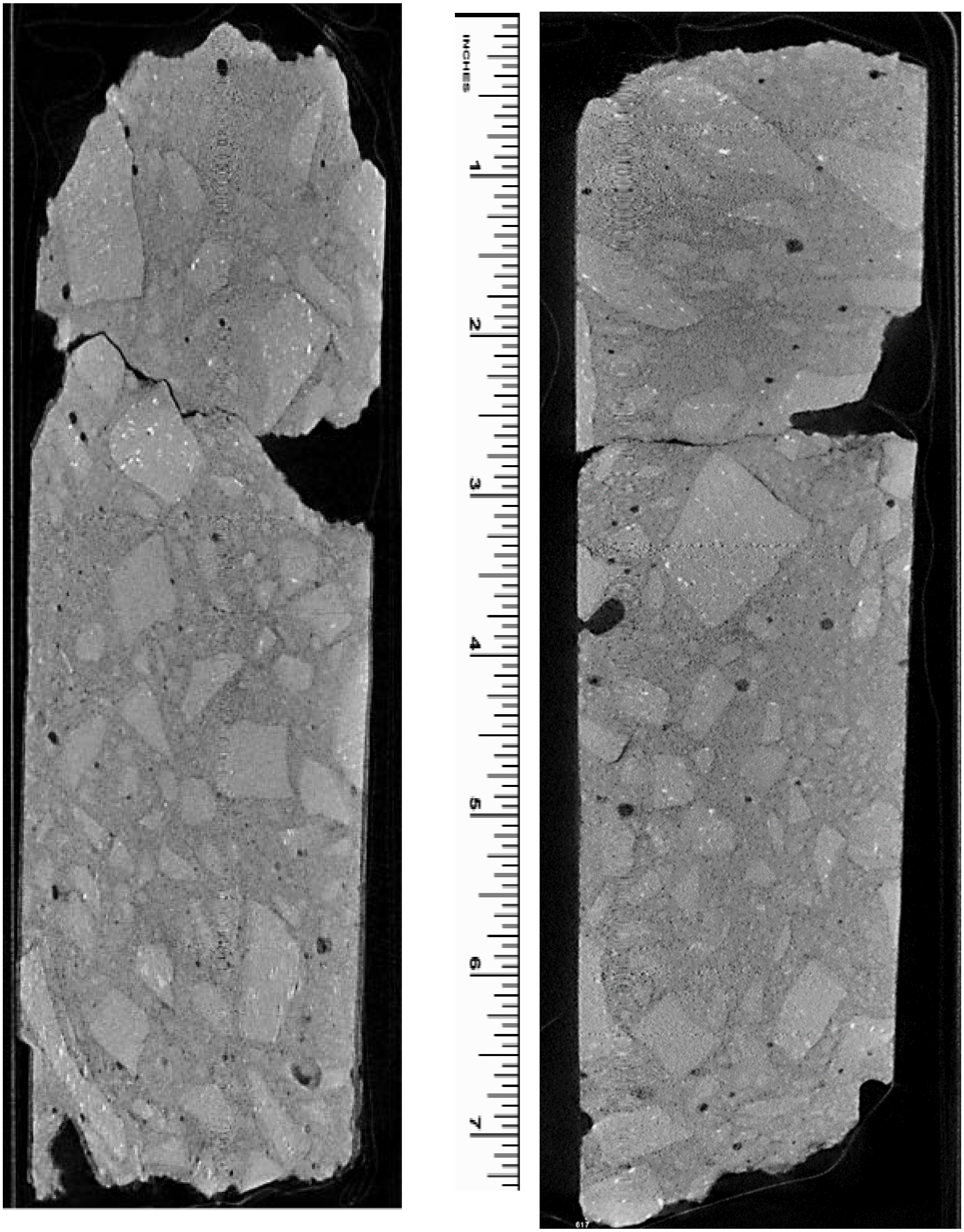
N4-D Distance from surface	(inches)	0.125	0.375	0.875	1.25	1.625	2.25	5	6	7
	(mm)	*3.2*	*9.5*	*22.2*	*31.7*	*41.3*	*57.2*	*127*	*152*	*178*
K in Leachate	**(mg/L)**	< 131	< 131	< 131	< 131	< 131	< 131	< 131	< 131	< 131
Na in Leachate	**(mg/L)**	< 24.3	< 24.3	< 24.3	< 24.3	< 24.3	< 24.3	< 24.3	< 24.3	< 24.3
Ca in Leachate	**(mg/L)**	906	924	593	723	231	299	79.2	185	100
N5-C Distance from surface	**(inches)**	**0.125**	**0.375**	**0.625**	**0.875**	**1.25**	**1.625**	**2**	**4**	**9**
	(mm)	*3.2*	*9.5*	*15.9*	*22.2*	*31.7*	*41.3*	*50.8*	*101.6*	*228.6*
K in Leachate	**(mg/L)**	< 131	< 131	< 131	< 131	< 131	< 131	< 131	< 131	< 131
Na in Leachate	**(mg/L)**	< 24.3	< 24.3	< 24.3	< 24.3	< 24.3	< 24.3	< 24.3	< 24.3	< 24.3
Ca in Leachate	**(mg/L)**	631	826	1290	960	1190	776	362	88.5	191

3.7 Core Imaging (X-ray Computed Tomography)

X-ray computed tomography (XCT) of core sections N3-D and N4-D indicated uniform profiles throughout the entire length of these samples. No macroscopic or internal degradation features (cracking or porosity or density gradations) were observed in any of the XCT images. The matrix-aggregate interfaces appear intact throughout the entire core sections. No delamination, cracking, low-density regions in the matrix were discernable as a function of distance from the Cross-over Tunnel wall surface exposed to the canyon exhaust environment.

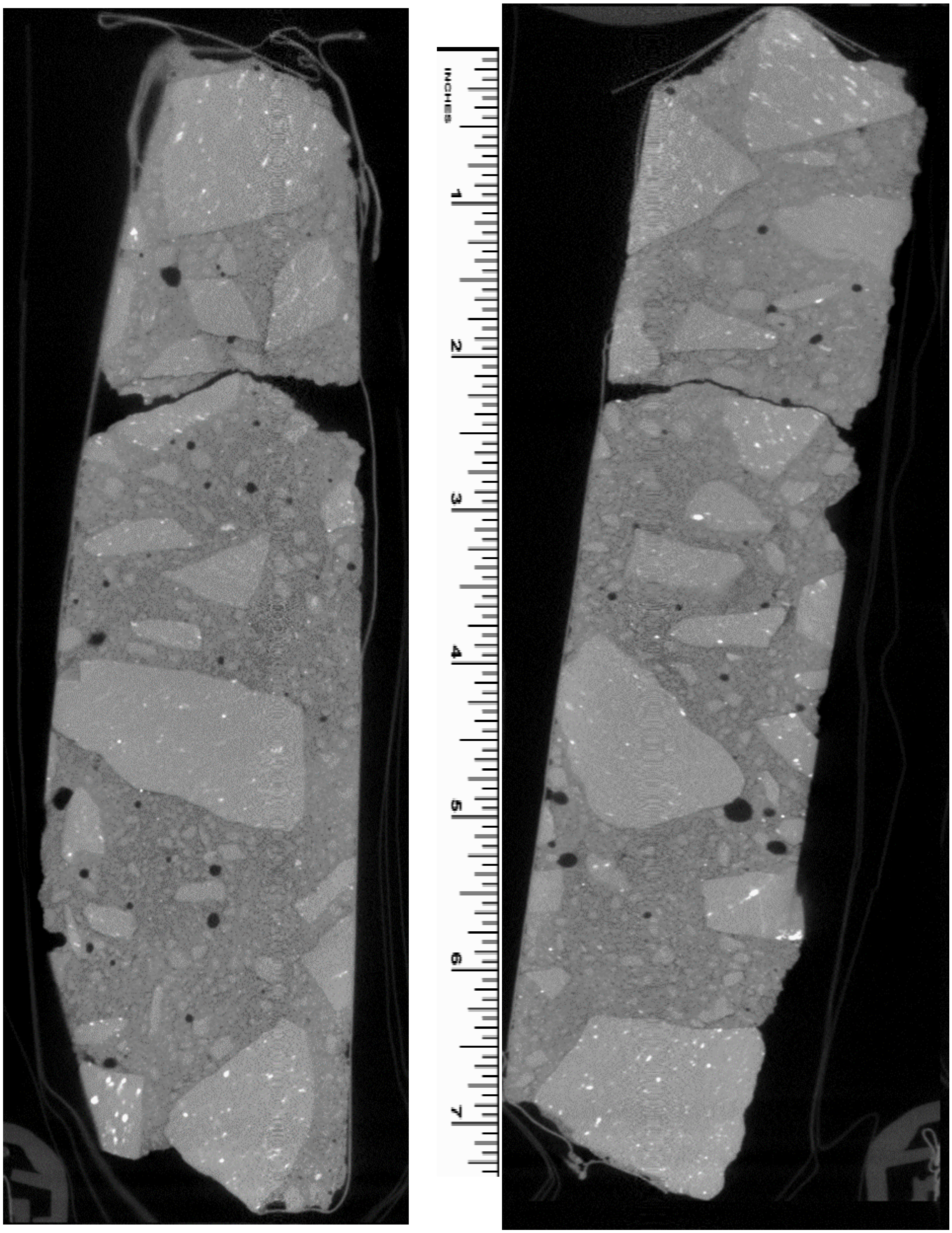
XCT images of two orthogonal planes in Core N3-D and Core N4-D are provided in Figure 3.7 and Figure 3.8, respectively. The N3-D images were taken on half of the cylindrical core retrieved from the wall. The N4-D images were taken from one-quarter of the cylindrical core retrieved from the wall. Both cores were in two pieces which were reassembled for the CT scans. They had been previously broken about 50 to 76 mm (2 to 3 inches) from the exposed surface as the result of sub-sampling techniques used to collected matrix material for radiological screening.

Black spots in Figure 3.7 and Figure 3.8 are voids present in the initial concrete placement. Schist (coarse aggregate) and quartz sand (fine aggregate) are angular features which are lighter in color than the hydrated cement matrix. Vertical and horizontal “rastering” features in these images are artifacts of the data collection and processing.



XZ plane YZ plane

Figure 3.7. XCT scan of core N3-D in both the XZ and YZ planes.



XZ plane YZ plane

Figure 3.8. XCT scan of core N4-D in both the XZ and YZ planes.

3.8 Concrete Microstructure

Cores N3-D, N4-D, and N5-C were examined by SEM and EDS as described in Section 2.9. General observations include: (1) the concrete in these core sections has a high porosity and microcracks interpreted as resulting from shrinkage (2) macrocracks in these core sections were the result of coring and SRNL sample handling (subsampling, cutting, grinding, and polishing), and (3) the matrix is a multiphase material that includes hydrated portland cement phases and unreacted particles of portland cement clinker.

Qualitative Ca/Si ratios of the bulk of the matrix are within the typical ranges for calcium silicate hydrates as determined by qualitative EDS. Area elemental analyses of the surfaces exposed to the canyon exhaust (between 0 mm and approximately 2.2 mm) indicated a mixture of typical cement phases (Ca, Si, Al, S, Fe, and Mg) and the presence of carbon. Carbon dioxide in the exhaust was assumed to be the carbon source and the EDS results were interpreted as carbonation of the matrix. However, additional investigation is necessary to confirm a single or multiple source of carbon. See Figure 3.9 to Figure 3.11.

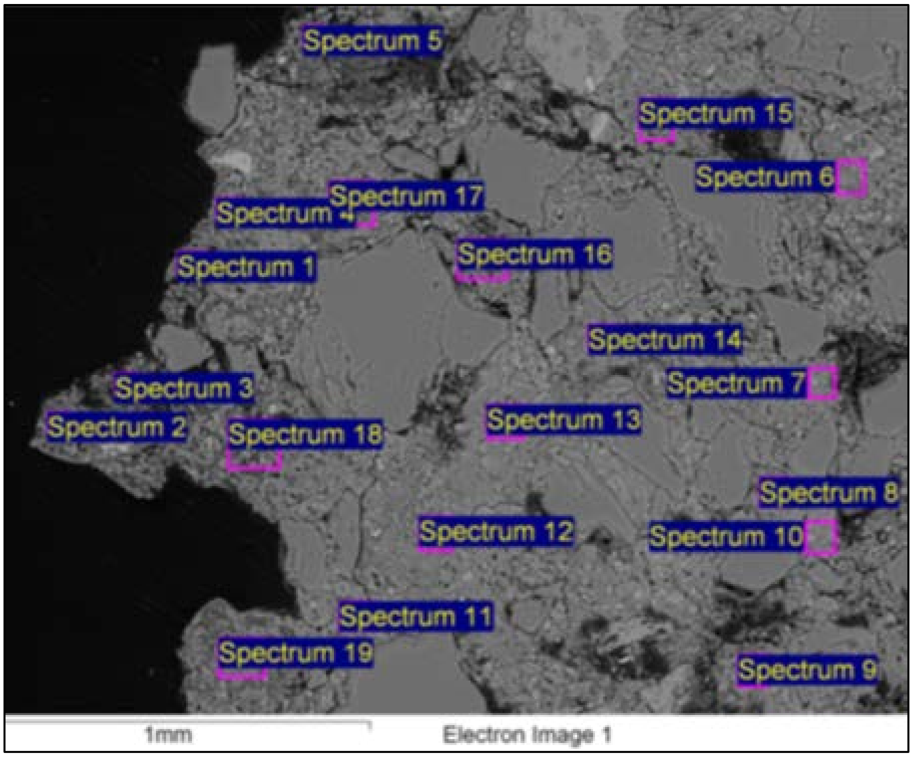
Images as a function of distance from the exposed surface are provided for cores N3-D, N4-D and N5-C in Figures 3-12 to 14, Figures 3-15 to 17 and Figure 3-18 to 21, respectively.

The exposed surfaces of each of the three cores examined had distinct features, however the matrices in cores N3-D and N4-D were similar about 500 µm below the surface (Figure 3-12 and 3-15, respectively). Surface layering was not evident on Core N3-D. Between 0 and 250 µm from the surface EDS area scan spectra indicate the presence of Ca, Si, Al, S and C. Matrix phases at the surface include: calcium aluminate sulfate hydrates and carbonated calcium aluminate sulfates and C-S-H phases.

Discrete layers were observed on the surface of core N4-D (Figure 3.15 to Figure 3.17). The outermost layer is discrete and made up of several phases based on high magnification particle morphologies and most likely contains a calcium aluminosulfate hydrate phases which appears to be partially carbonated in addition to C-S-H (Figure 3.16). The second layer or lens is higher in carbon/carbonate compared to the outer layer. The third layer (approximately 150 µm from the exposed surface) contains Ca and Si in ratios typical of hydrated portland cement but also contains some carbon suggesting carbonation (Figure 3.17).

Disruption of the matrix due to expansive reactions, e.g., alkali silica reaction, was not observed in any of the samples examined. Localized cracks and irregular shaped voids were attributed to initial porosity and shrinkage that was inferred to indicate a relatively high water to cement ratio in the initial concrete mix (Figure 3.9 to Figure 3.11). However, Core N5-D contained small features that were indicative of drying not associated with initial shrinkage. Although these features resembled desiccated alkali-silica gel EDS spectra did not support an ASR interpretation (Figure 3-20 upper left image). Based on the SEM petrographic evaluation coupled with EDS spectra, ASR was not observed in the core sections examined. However, the potential exists that soluble alkali in the original portland cement clinker could react with decalcified C-S-H gel resulting from exposure to nitric acid. No ASR was associated with the schist or quartz aggregates. Consequently, ASR was not observed in theses cores

Core N5-C images contained unidentified features which were too thin walled to obtain reliable EDS spectra. These features were observed in localized regions of the matrix between the surface and 35 mm (about 1.5 inches) from the surface. See Figure 3-21.



Spectrum	In stats.	C	N	O	Mg	Al	Si	S	Cl	K	Ca	Fe	Total
Spectrum 1	Yes	37.38	0.00	39.87	0.29	0.87	4.50	0.63	0.14	0.04	15.86	0.42	100.00
Spectrum 2	Yes	42.66	0.00	36.12	0.46	1.39	4.47	0.36	0.19	0.06	13.36	0.92	100.00
Spectrum 3	Yes	61.44	0.00	23.22	0.20	0.73	3.19	0.25	0.12	0.12	10.17	0.56	100.00
Spectrum 4	Yes	35.93	0.00	39.35	0.40	1.46	5.46	0.51	0.15	0.04	15.63	1.07	100.00
Spectrum 5	Yes	48.40	0.00	34.36	0.34	1.06	5.94	0.23	0.15	0.04	8.95	0.54	100.00
Spectrum 6	Yes	25.48	0.00	45.85	0.61	1.48	7.91	0.36	0.13	0.10	17.31	0.76	100.00
Spectrum 7	Yes	29.52	0.00	43.75	0.47	1.50	8.62	0.24	0.09	0.12	15.20	0.49	100.00
Spectrum 8	Yes	26.05	0.00	45.97	0.42	1.45	7.84	0.34	0.09	0.08	16.56	1.20	100.00
Spectrum 9	Yes	34.68	0.00	40.80	0.48	1.13	6.76	0.26	0.12	0.14	15.06	0.58	100.00
Spectrum 10	Yes	27.13	0.00	45.94	0.33	1.40	7.46	0.32	0.08	0.08	16.24	1.02	100.00
Spectrum 11	Yes	25.89	0.00	44.76	0.49	1.29	7.32	0.61	0.15	0.07	18.64	0.78	100.00
Spectrum 12	Yes	24.77	0.00	45.60	0.49	1.57	7.49	0.66	0.12	0.10	18.21	1.00	100.00
Spectrum 13	Yes	23.50	0.00	46.56	0.42	1.45	8.34	0.36	0.11	0.20	18.18	0.88	100.00
Spectrum 14	Yes	24.28	0.00	46.33	0.77	1.96	8.48	0.29	0.11	0.11	16.40	1.26	100.00
Spectrum 15	Yes	28.89	0.00	43.74	0.51	1.88	7.47	0.33	0.15	0.09	15.99	0.95	100.00
Spectrum 16	Yes	41.92	0.00	36.78	0.38	1.03	6.12	0.33	0.16	0.06	12.65	0.57	100.00
Spectrum 17	Yes	30.97	0.00	41.55	0.35	1.56	6.71	0.45	0.12	0.10	17.13	1.05	100.00
Spectrum 18	Yes	43.12	0.00	36.94	0.17	0.96	7.70	0.40	0.12	0.05	9.89	0.63	100.00
Spectrum 19	Yes	39.93	0.00	36.91	0.31	0.93	5.58	0.56	0.14	0.08	15.00	0.55	100.00
Mean		34.31	0.00	40.76	0.42	1.32	6.70	0.39	0.13	0.09	15.07	0.80	100.00
Std. deviation		10.07	0.00	5.87	0.14	0.33	1.51	0.14	0.03	0.04	2.85	0.26	
Max.		61.44	0.00	46.56	0.77	1.96	8.62	0.66	0.19	0.20	18.64	1.26	
Min.		23.50	0.00	23.22	0.17	0.73	3.19	0.23	0.08	0.04	8.95	0.42	

Figure 3.9 Image of core N3-D (top) and elemental analysis of selected areas between 0 mm and approximately 2.2 mm from surface exposed to the canyon exhaust (bottom).

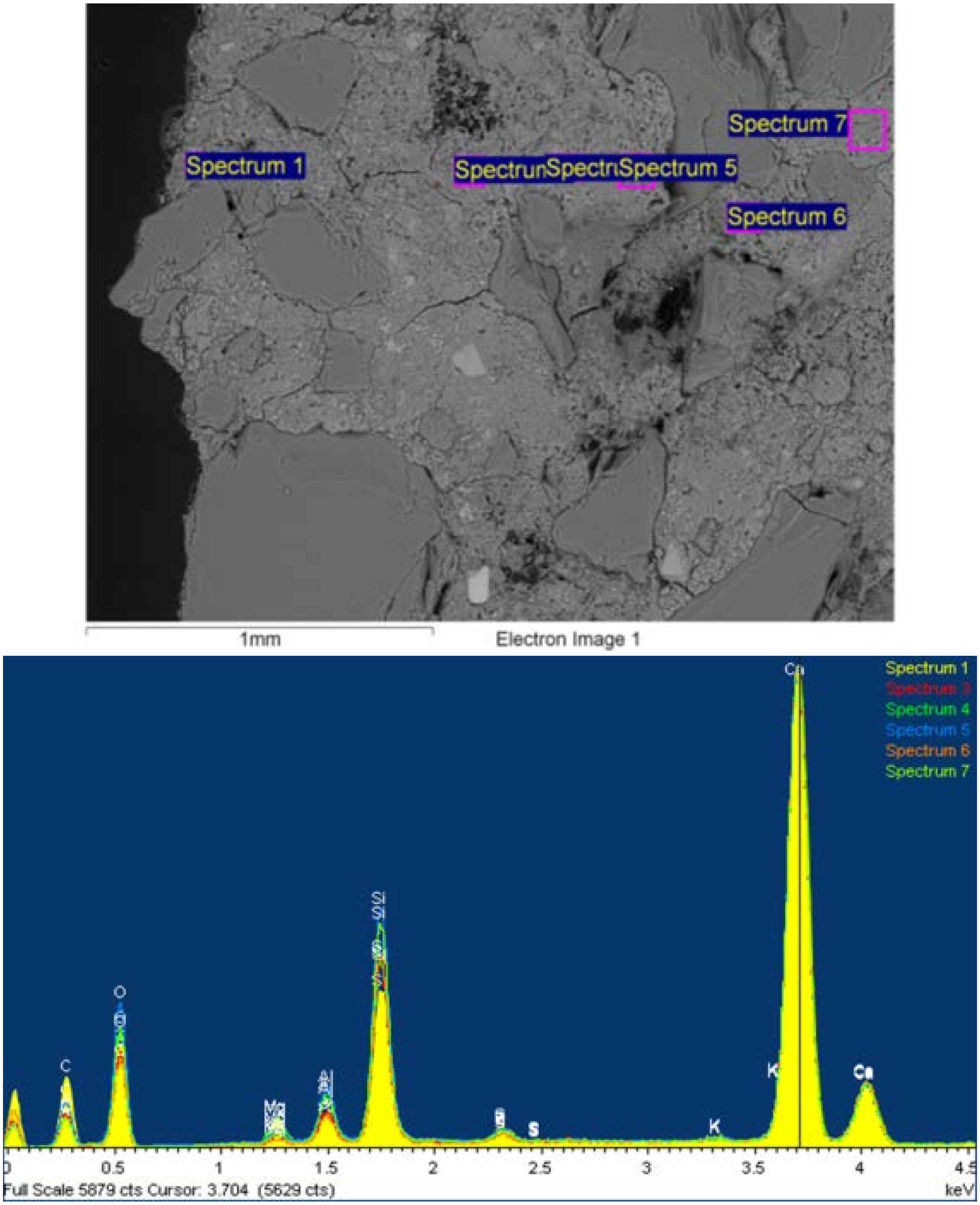
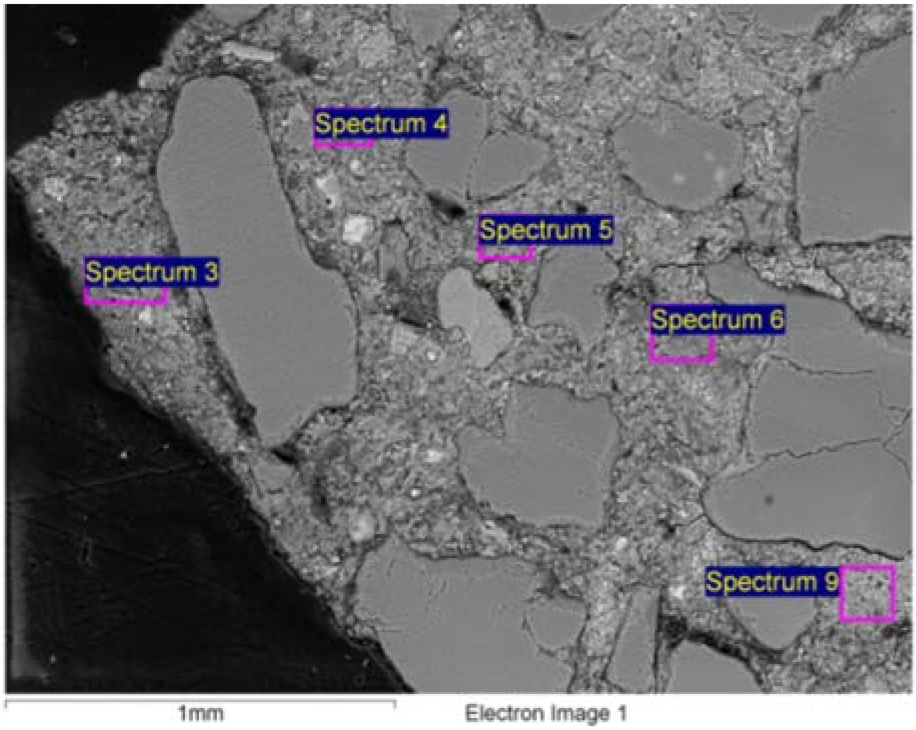


Figure 3.10. Core N4-D image (top) and elemental analysis of selected areas between 0 mm and approximately 2.2 mm from surface exposed to the canyon exhaust (bottom).



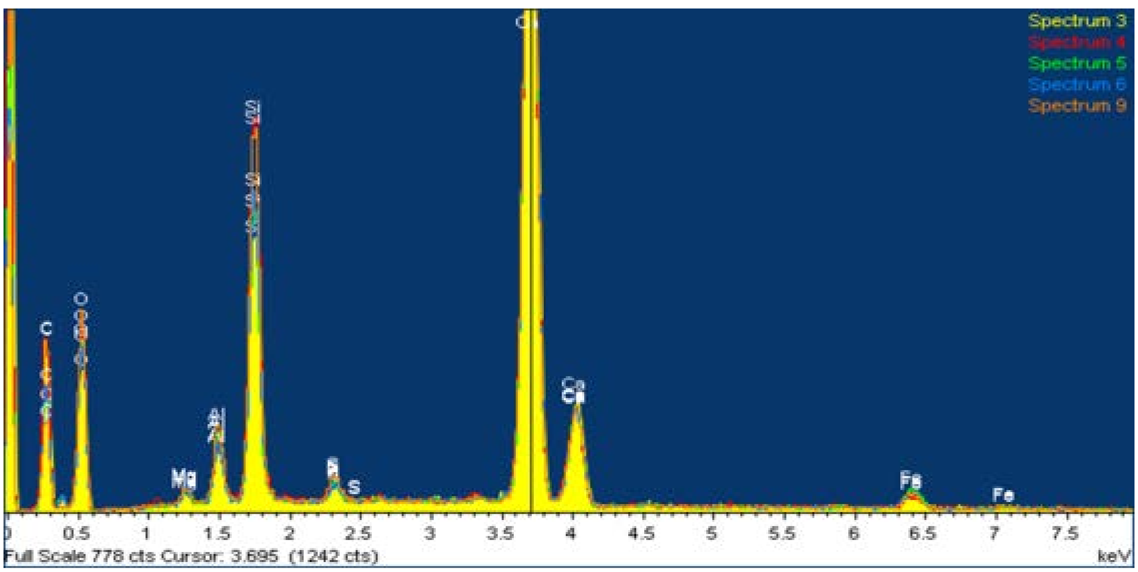
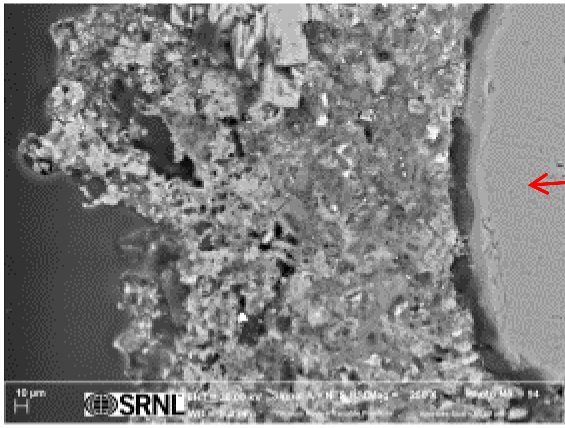
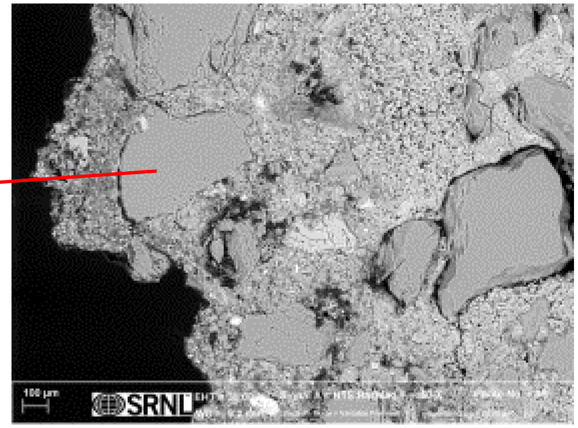


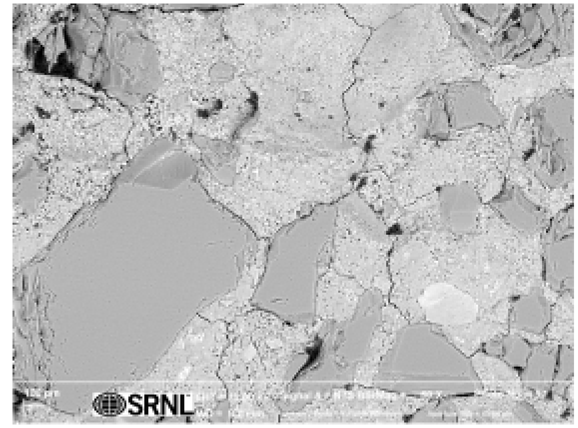
Figure 3.11. Core N5-C image (top) and elemental analysis of selected areas between 0 mm and approximately 2.2 mm from surface exposed to the canyon exhaust (bottom).



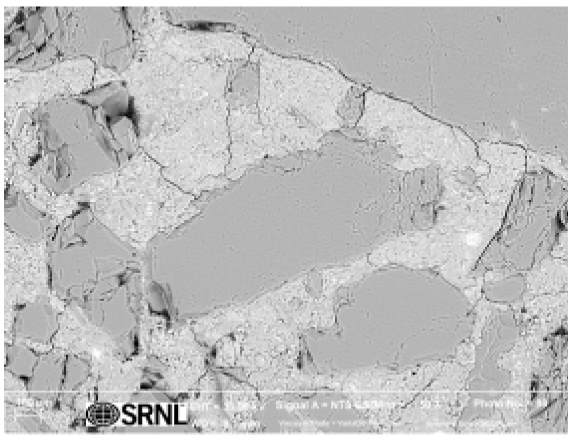
N3-D Surface shows a porous layer with a calcium sulfate and sulfoaluminate layer



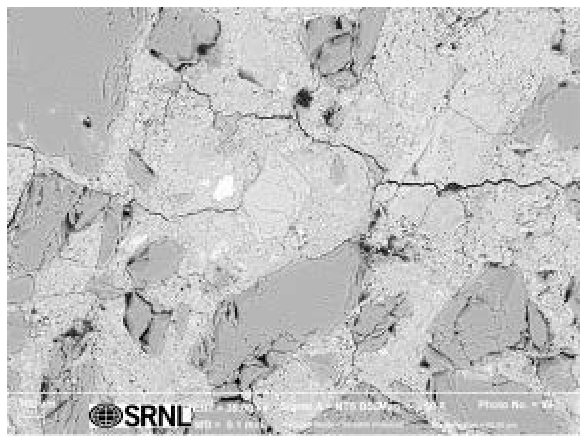
N3-D 0 to 250 µm from exposed surface at lower magnification than upper left mictrograph



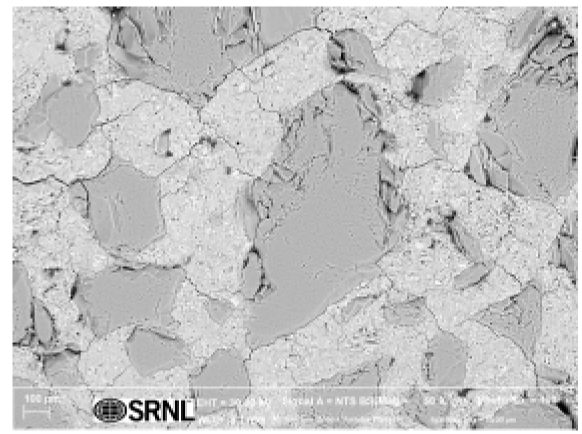
N3-D 4mm from exposed surface



N3-D 6 mm from exposed surface



N3-D 8 mm from exposed surface



N3-D 10 mm from exposed surface

Figure 3.12. SEM micrographs of core section N-3-D from various distances from exposed surface.

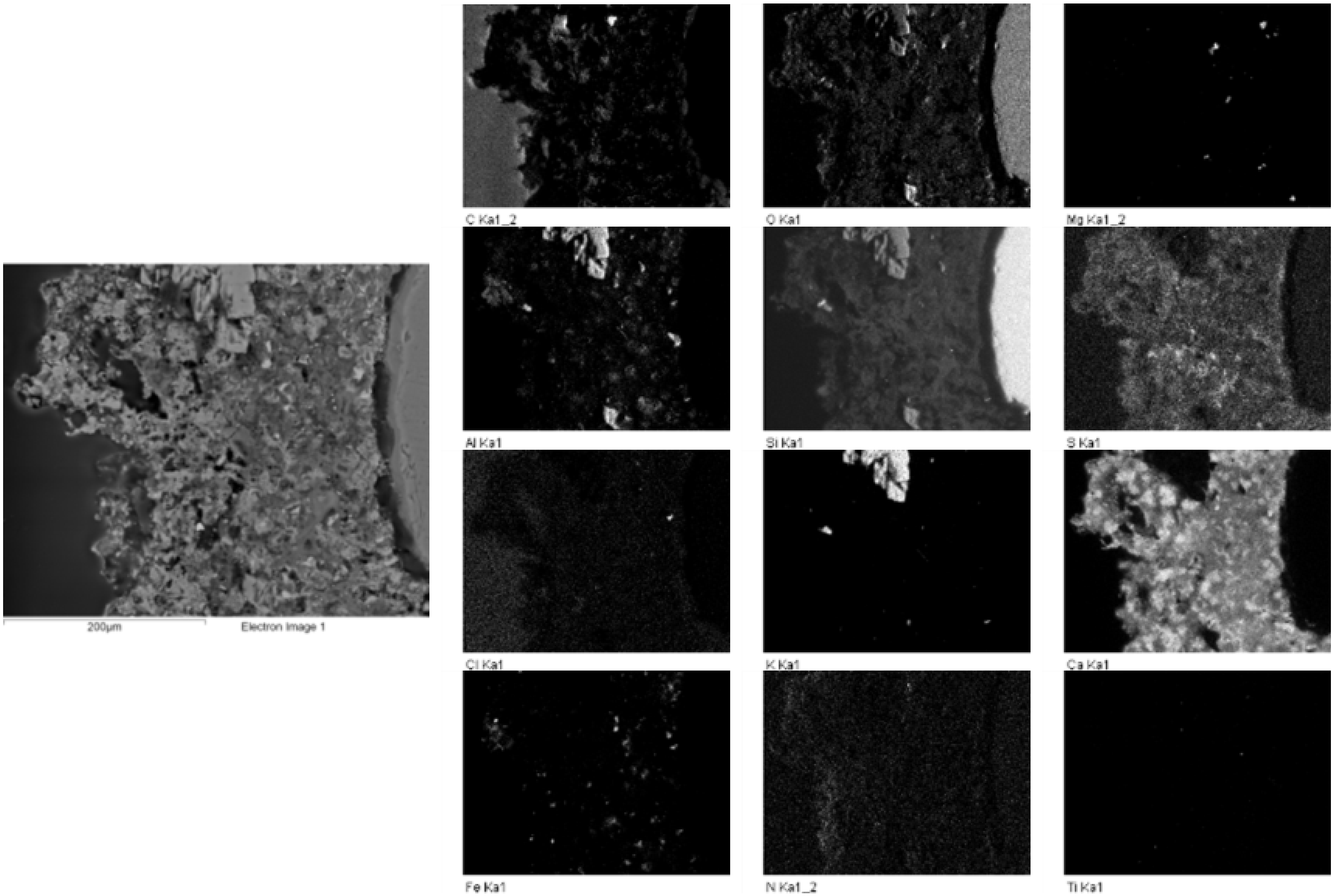
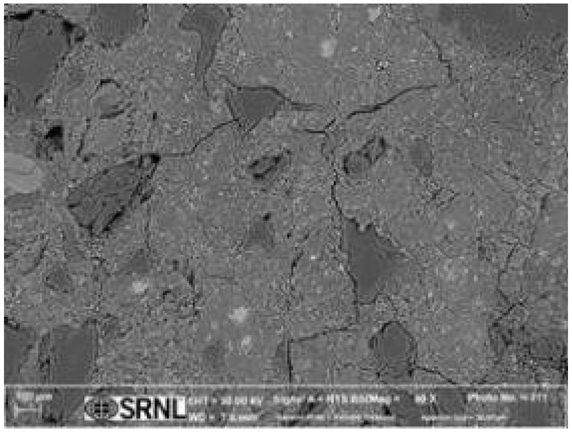
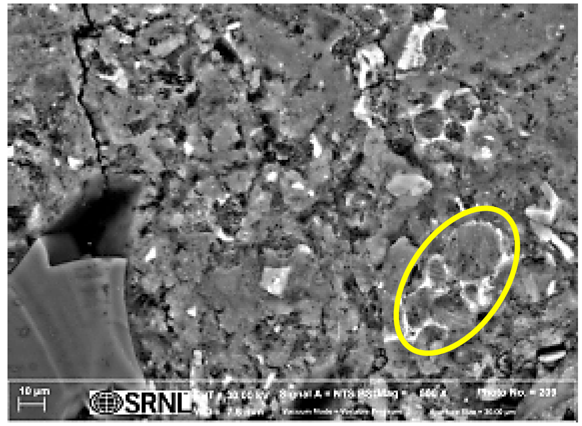


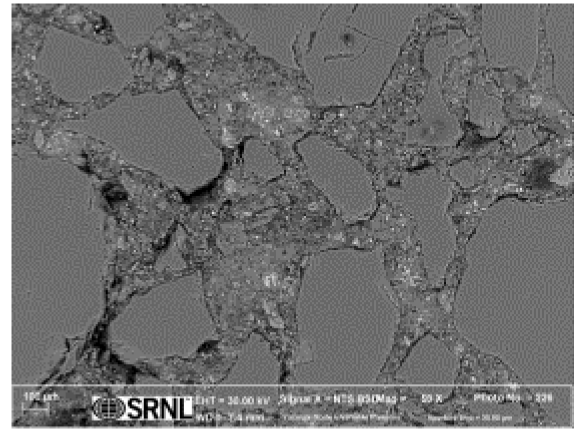
Figure 3.13. Elemental map of core N3-D surface layer (0 to 0.05 mm from exposed surface) indicating the presence of Ca, S, Si, Al, and carbon (bright areas on elemental images).



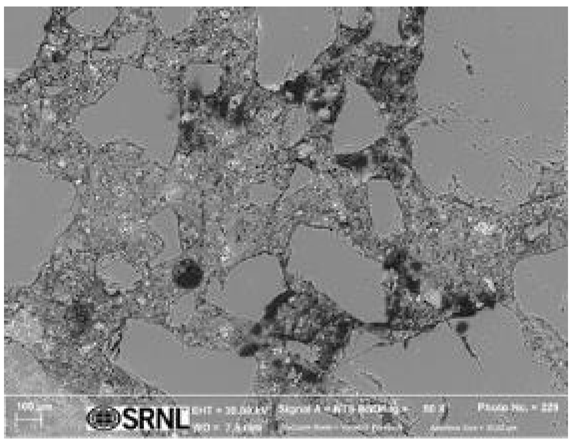
N3-D 25 mm (1 in.) from exposed surface



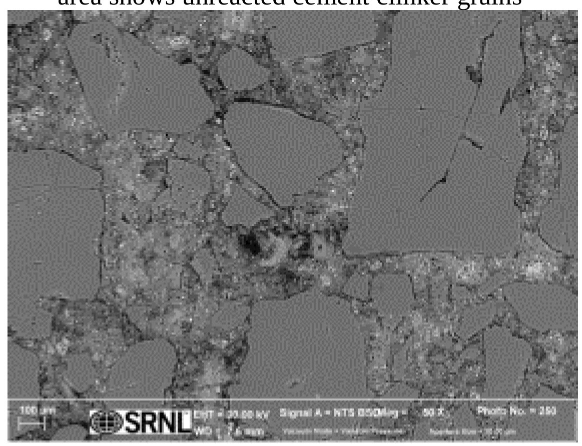
N3-D 25 mm (1 in.) from exposed surface. Circled area shows unreacted cement clinker grains



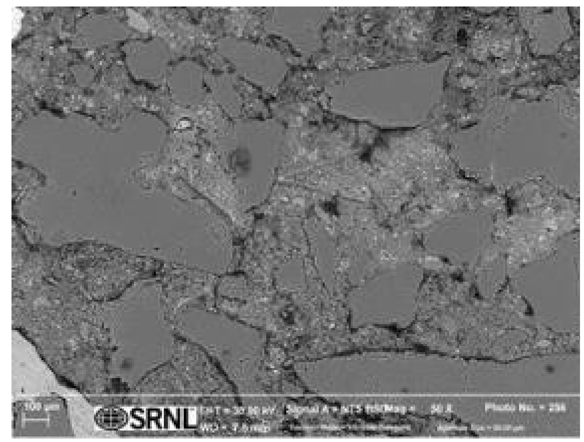
N3-D 85 mm (3.4 in.) from exposed surface



N3-D 100 mm (4 in.) from exposed surface

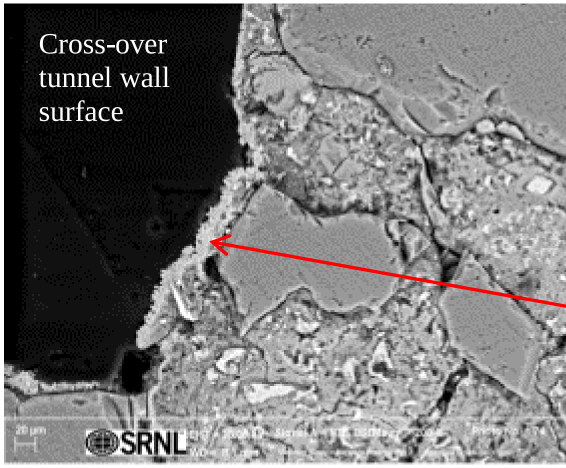


N3-D 180 mm (7 in.) from exposed surface

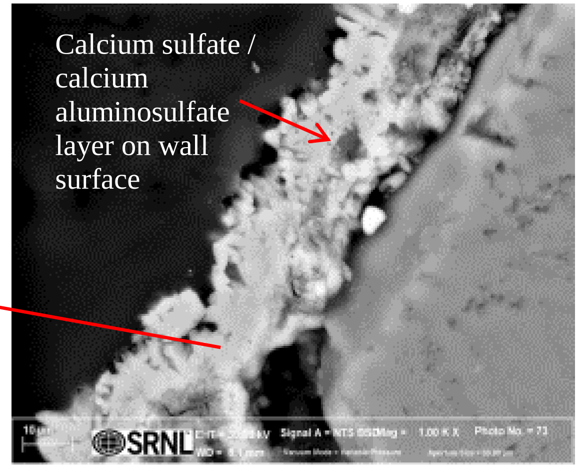


N3-D 200 mm (7.9 in.) from exposed surface

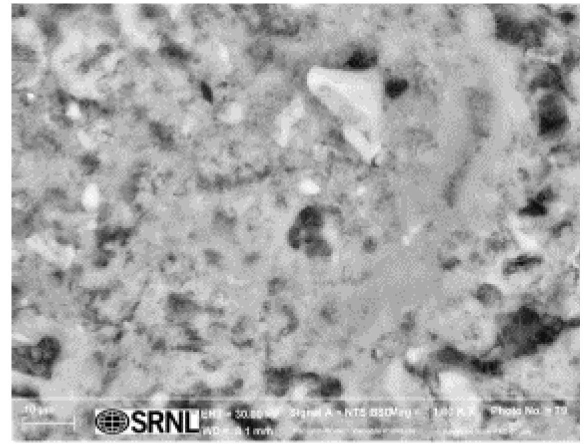
Figure 3.14. SEM micrographs of core N-3-D illustrating porous matrix. Black areas are pores, initial voids, and cracks introduced during coring and sample preparation.



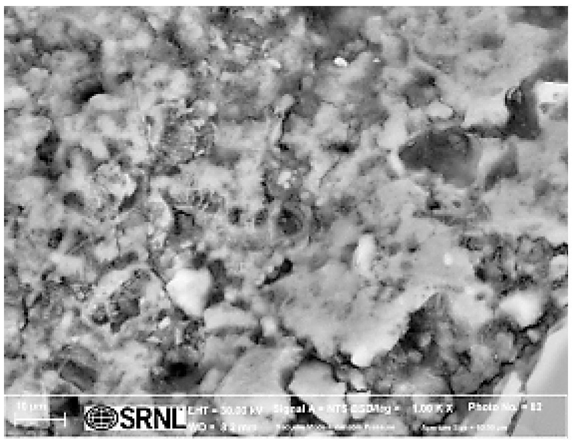
N4-D surface



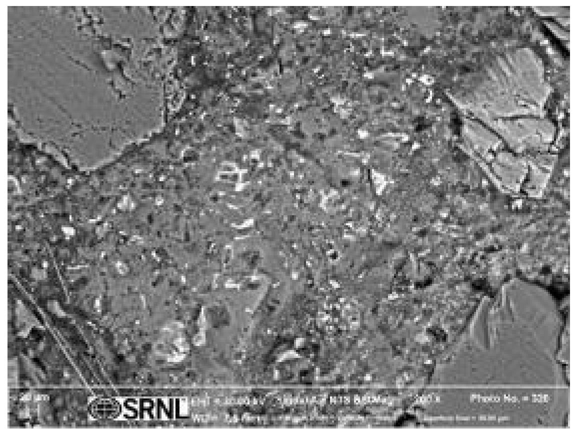
N4-D surface



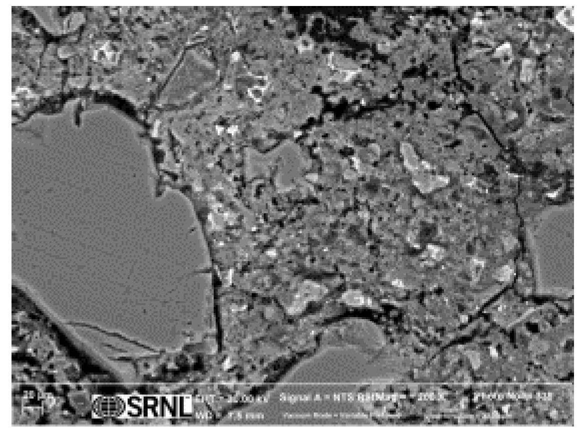
N4-D 1mm (0.04 in.) from exposed surface



N4-D 20 mm (0.75 in.) from exposed surface



N4-D 130 mm (5.1 in) from exposed surface Crack filling (linear features lower left) and secondary mineralization around particles or pores (bright curved lines)



N4-D 190 mm (7.5 in) from exposed surface secondary alteration around particles or pores (bright curved lines)

Figure 3.15. SEM micrographs of core N-4-D as a function of distance from the exposed surface.

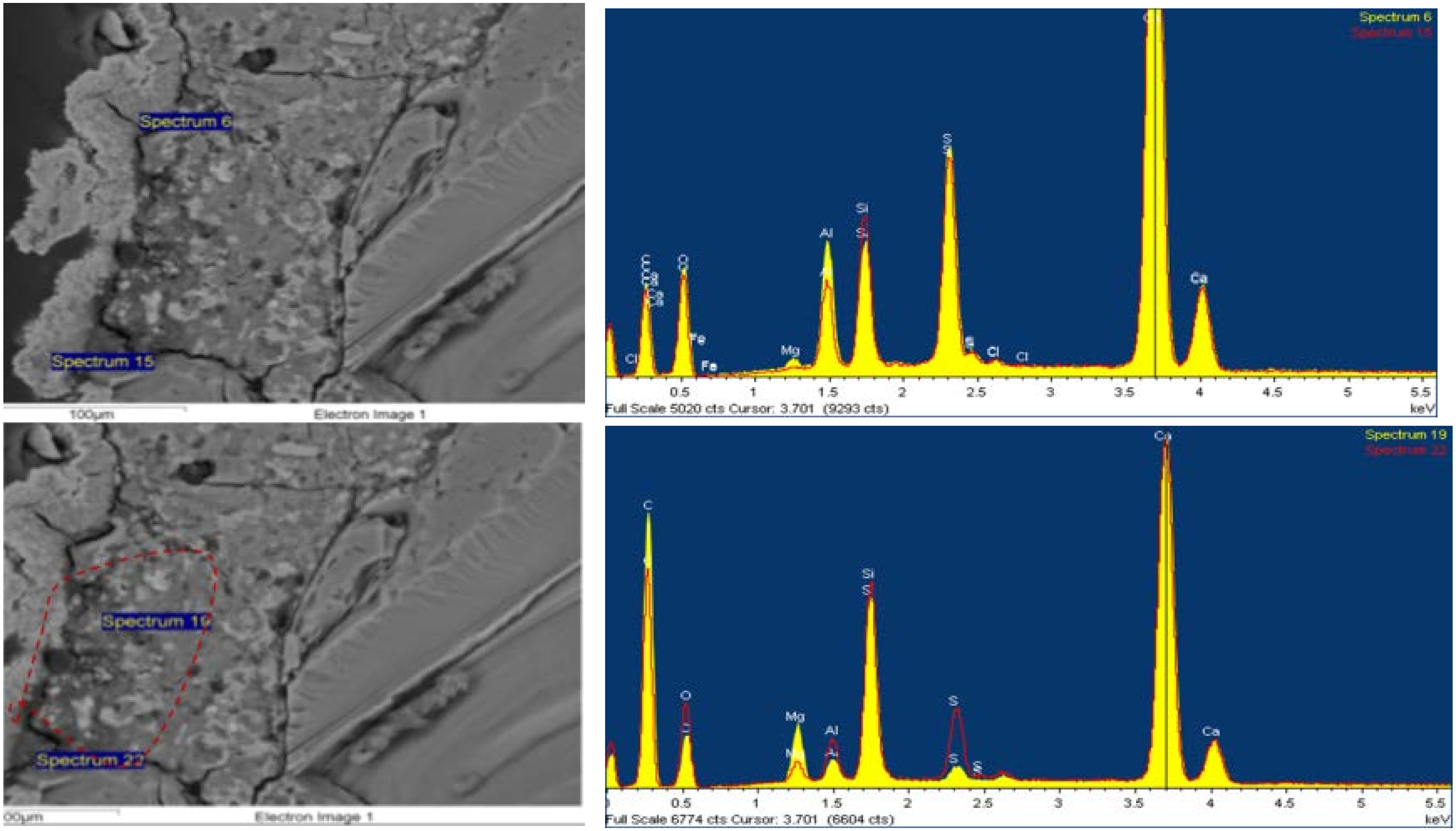


Figure 3.16. Elemental map of core N4-D surface layer (0 to .3 mm from exposed surface) indicating presence of Ca, S, Si, Al C surface layer (top) Si, Al, and a near surface lens of carbonated matrix phases Ca, Si C, Mg, carbon (bottom).

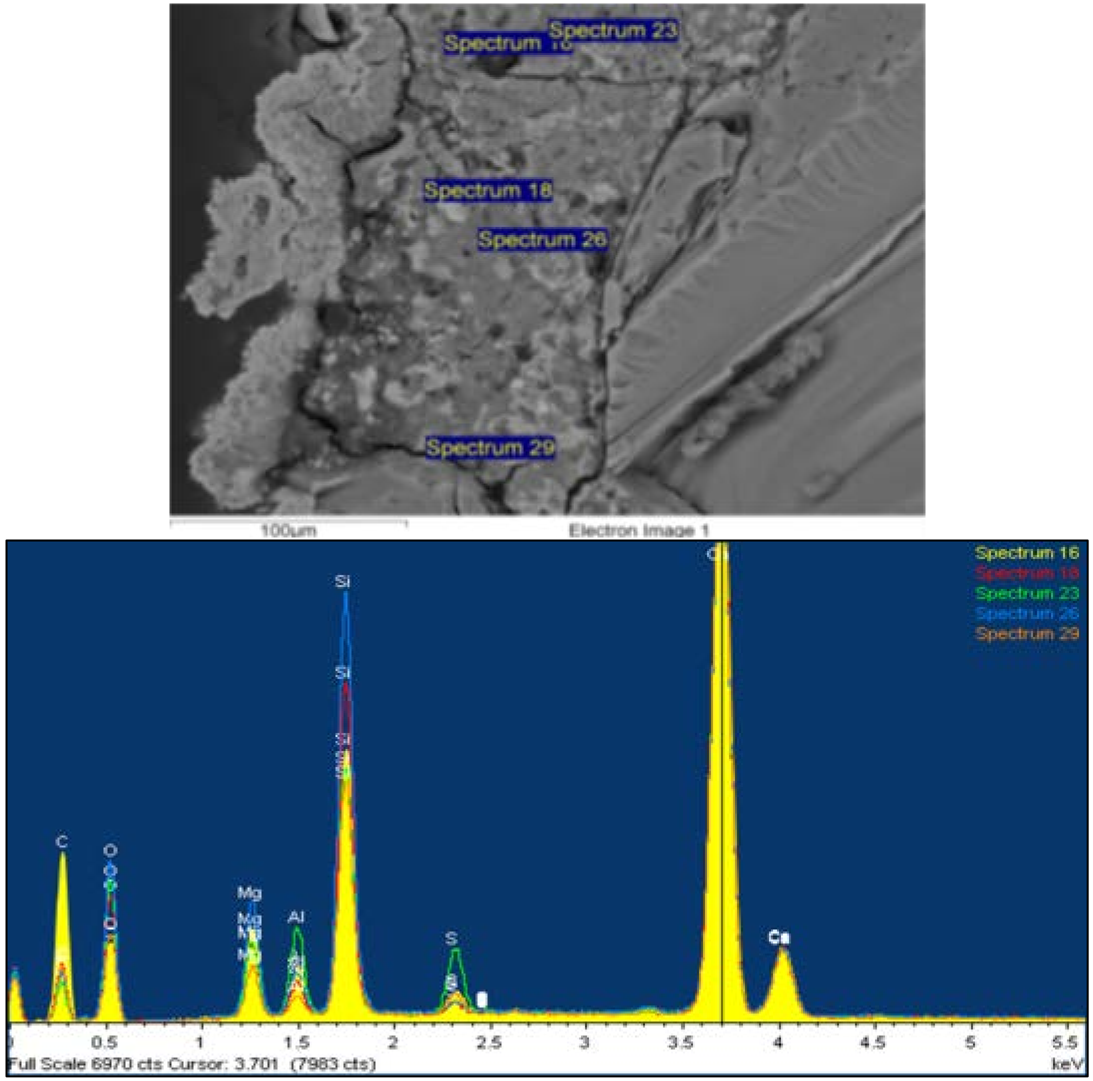
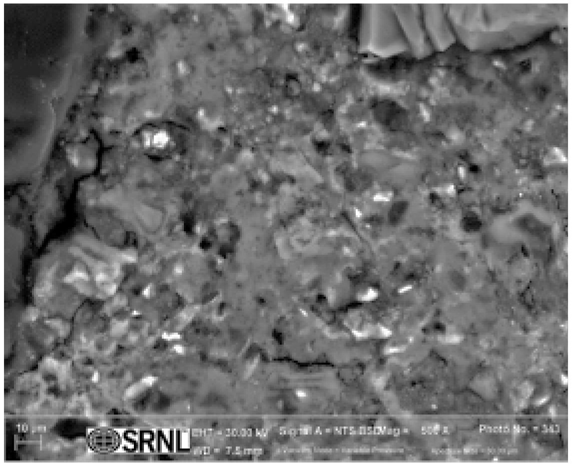
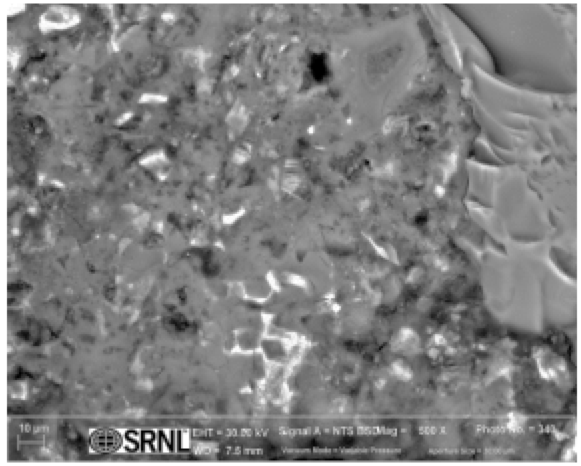


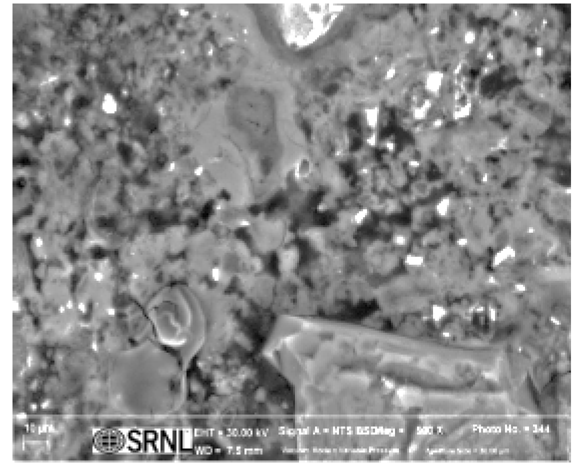
Figure 3.17. Elemental map of core N4-D near surface partially carbonated cement matrix phases (Ca, Si, C S, Al, Mg) in contact with a quartz sand grain.



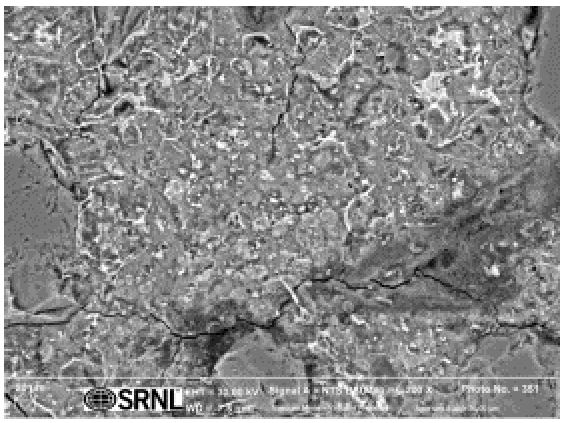
N5-C surface



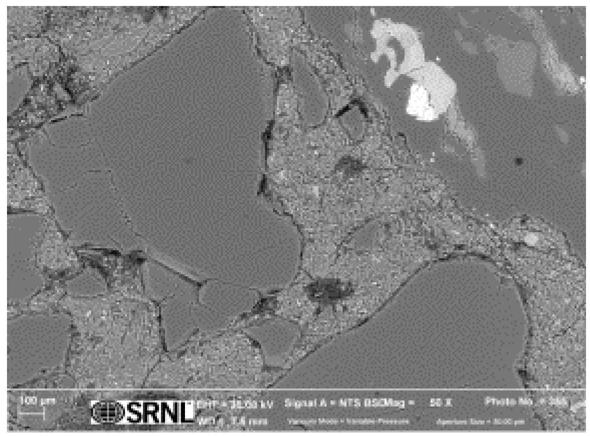
N5-C surface



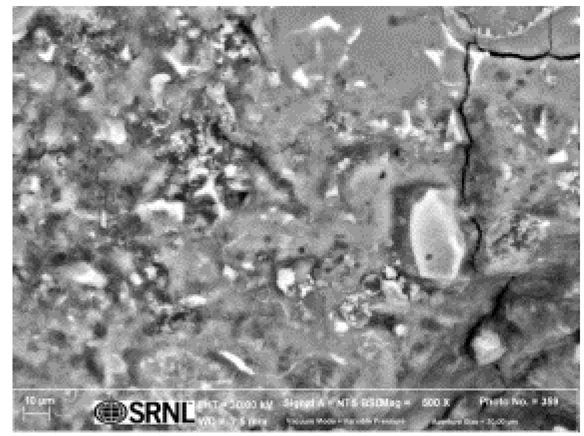
N5-C 2 mm (0.08 in.) from exposed surface



N5-C 6 mm (0.24 in.) from exposed surface

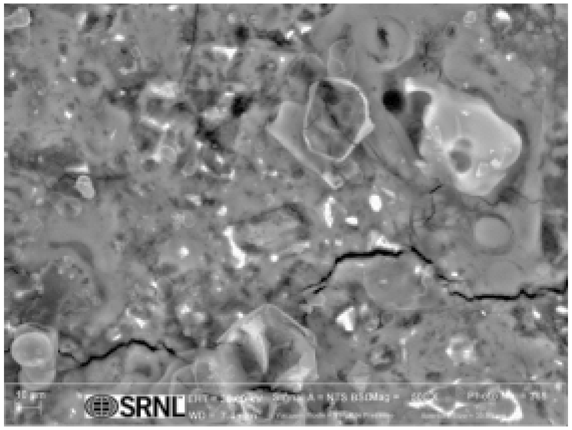


N5-C 10 mm (0.4 in.) from exposed surface

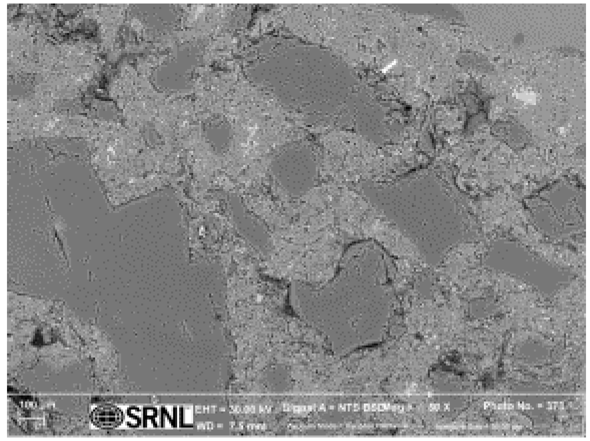


N5-C 20 mm (0.78 in.) from exposed surface

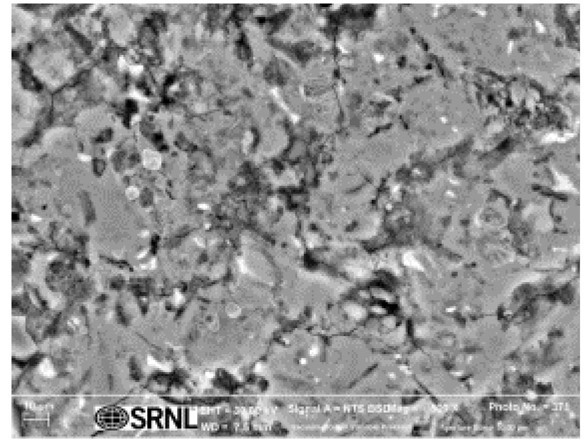
Figure 3.18. SEM micrographs of core N-5-C as a function of distance from the exposed surface.



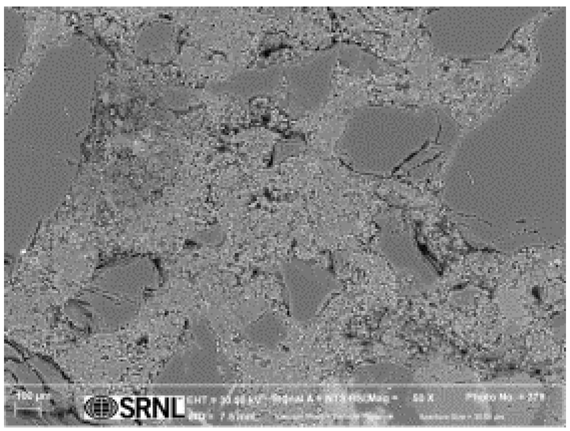
N-5C 35 mm (1.4 in.) from exposed surface



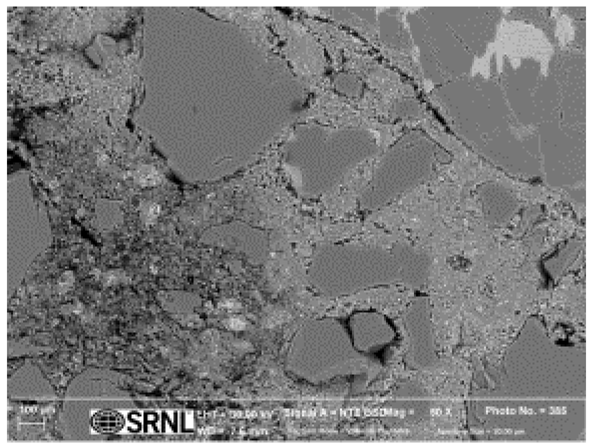
N5-C 60 mm (2.4 in.) from exposed surface



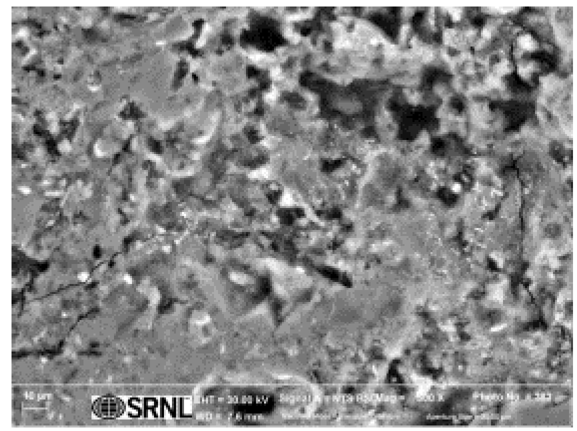
N5-C 60 mm (2.4 in.) from exposed surface



N5-C 80 mm (3.1 inches) from exposed surface

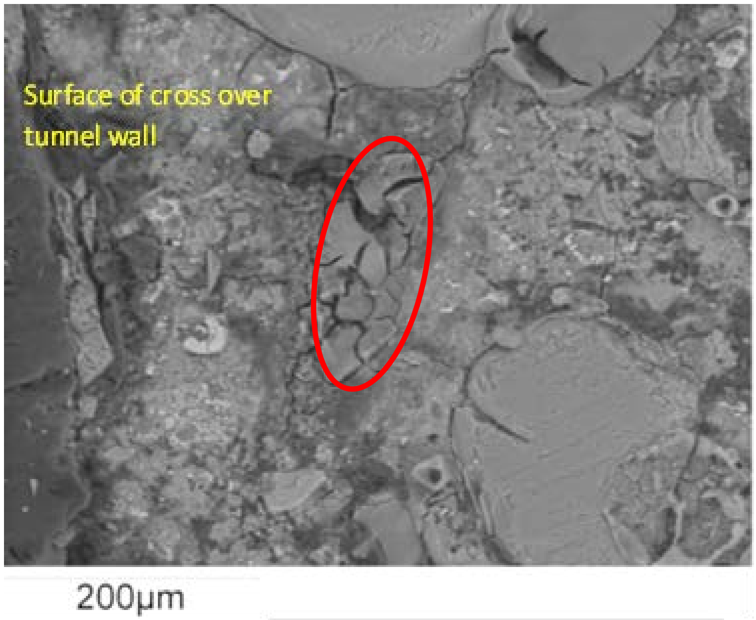


N5-C 100 mm (3.9 inches) from exposed surface

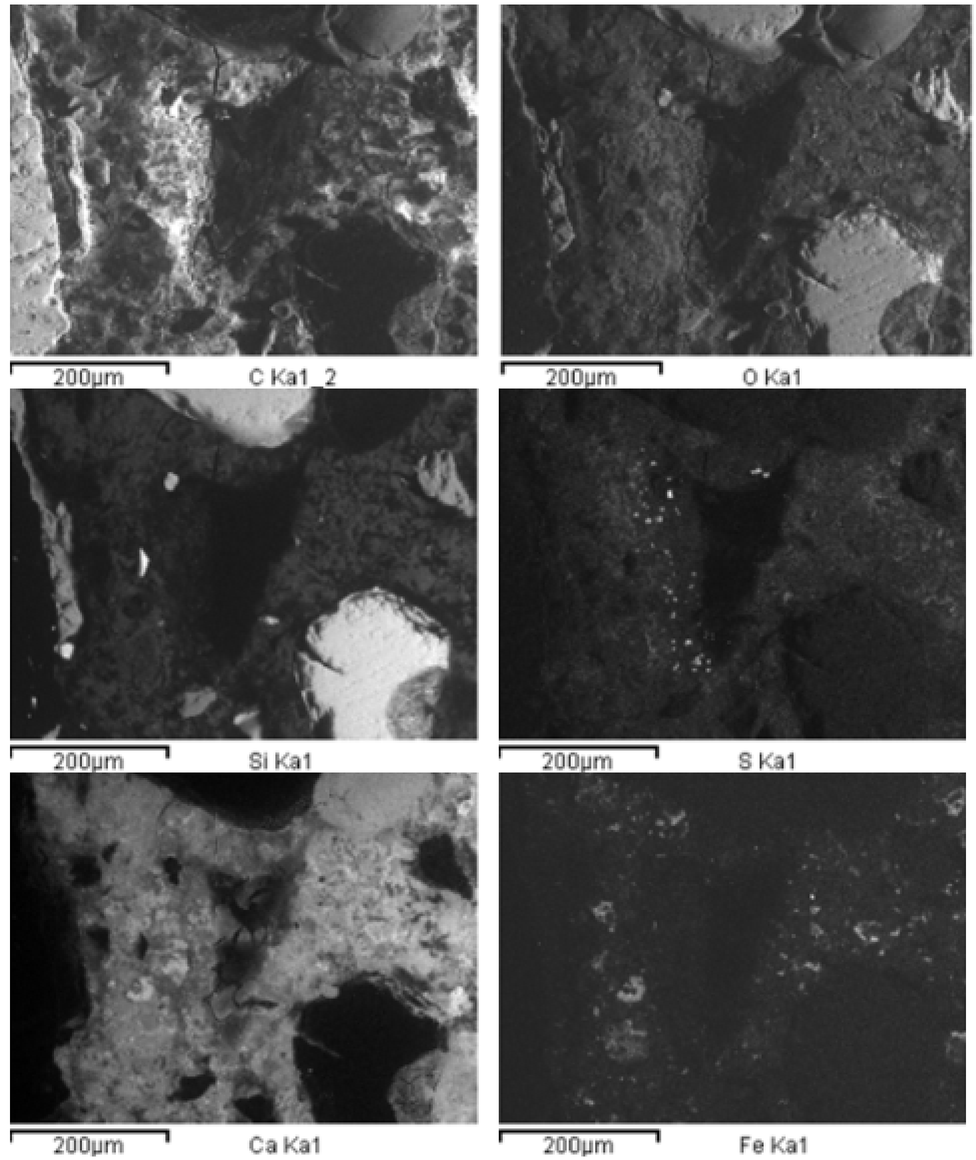


N5-C 100 mm (3.9 inches) from exposed surface

Figure 3.19. SEM micrographs of core N-5-C as a function of distance from the exposed surface.



ASR-like feature
Region outlined in red has morphology typical of ASR but does not contain silica. This area is surrounded by material rich in Ca and carbon.



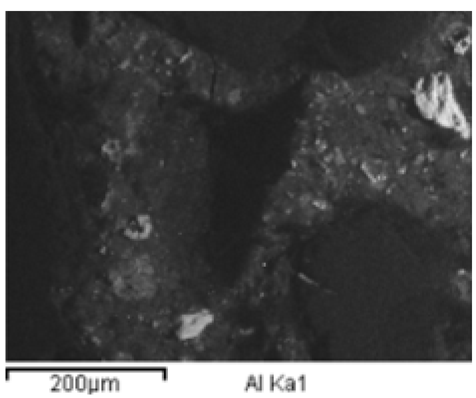


Figure 3.20. Example of unexplained features in core N5-C such as hollow Si-O and Ca-C-O features and tube-like structures.

.

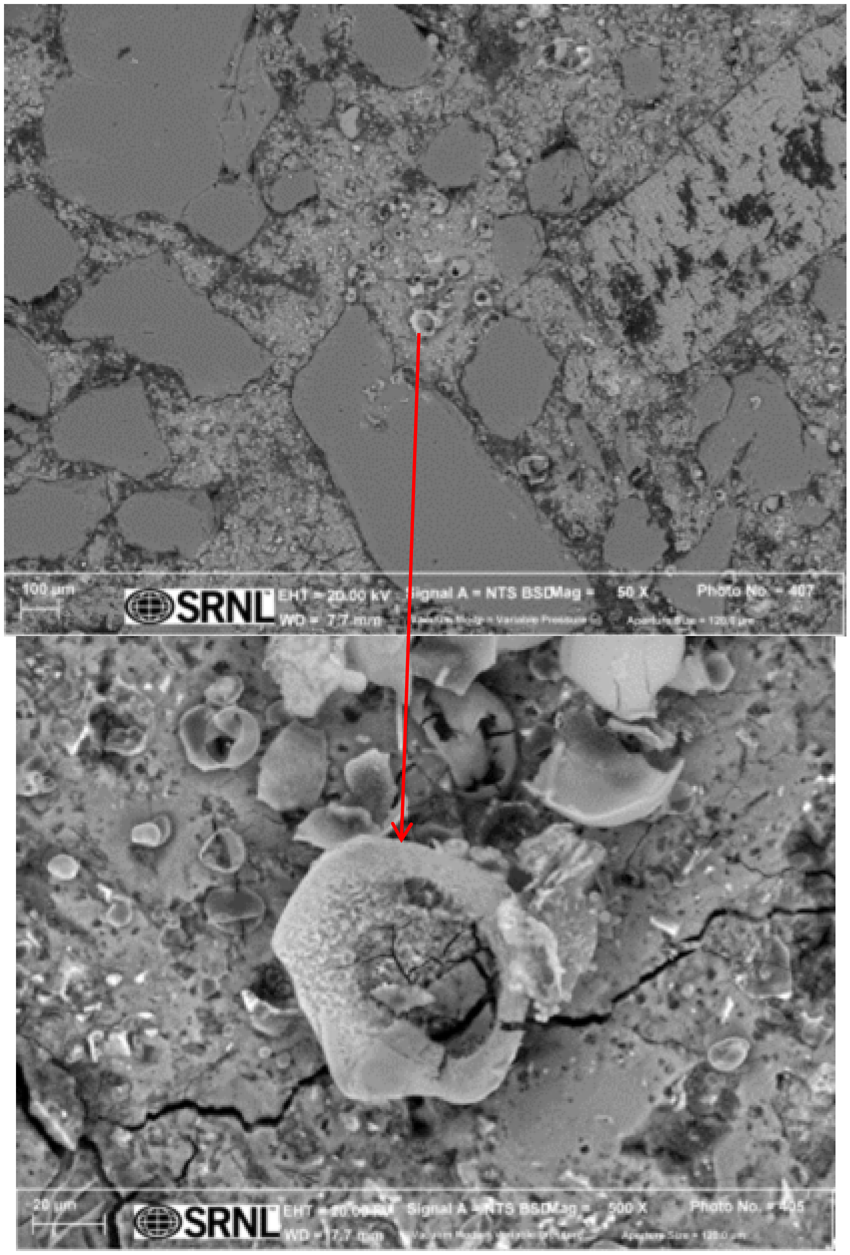


Figure 3.21. Images of tube-like structures on the surface of core N5-C at a distance of 35 mm from the exposed surface. Structure of tube interior suggests an organic origin and possible impurities in the concrete sand.

4.0 Results of Clean North Wall Core Sections

4.1 Mechanical and Physical Properties

Compressive strength, porosity, density, and UPV results for the clean sections of the 221-H Personnel Tunnel north wall cores are tabulated in Table 4-1. The 29 compressive strength measurements and values corrected for coring effects were obtained from core sections that were collected from 12 locations in the north wall.

The mean value for the as measured/reported data set was 15.2 MPa (2208 psi) and the standard deviation was 1.8 MPa (263.2 psi). The upper 95% mean value was 15.9MPa (2308 psi) and the lower 95% mean value was 14.5 MPa (2108 psi). The mean value for the 29 measurements corrected for geometry and coring damage was 16.1 MPa (2336 psi) and the standard deviation was 1.9 MPa (278.7 psi). The upper 95 % mean value for the corrected compressive strength data was 17.3 MPa (2515 psi) and the lower 95% mean value was 14.9 MPa (2156 psi).

Density (unit weight) was measured on 31 core sections. The mean density was 2269.9 kg/m^3 (141.7 lbs/ft^3). The standard deviation was 23.5 kg/m^3 (1.46 lbs/ft^3). The upper and lower 95 % mean values were 2277.8 kg/m^3 (142.2 lbs/ft^3) and 2261.8 kg/m^3 (141.2 lbs/ft^3). The data tested positive for a normal distribution.

Porosity that transmits moisture as the result of wetting and drying was measured on 12 north wall core sections. The data tested positive for a normal distribution. The mean transmissive porosity for this data set was 18.6 volume percent. The standard deviation was 1 volume percent and the upper and lower 95% mean values were 19.2 and 17.9 volume percent, respectively.

UPV measurements were made on 15 clean core sections from north wall. Multiple measurements were made on each core section, and the average value for each core section is tabulated in Table 4-1. The mean value was 36,141 m/s (11,856 ft/s) with a standard deviation of 287 m/s (942.3 ft/s).

UPV data sheets are included in Appendix D. Compressive strength, density and porosity data sheets are included in Appendix E.

Table 4-1. Mechanical and physical properties of concrete core sections from the north wall of the 221-H Personnel Tunnel.

Core Location	Compressive Strength Sample ID 221-H-PT3-	Density as reported (lbs/cft)	Porosity (vol. %)	Compressive Strength (psi) As Measured	Compressive Strength (psi) Corrected for drilling damage*	UPV Average** (ft/s)
N1	N1-A	144	--	2480	2629	--
	N1-B (US ERDC)	143	--	--	--	13,350
	N1-C	141	--	2280	2417	--
	N1-CC	--	17.8	--	--	--
	N1-D	--	--	--	--	--
N2	N2-A	140	--	2080	2161	--
	N2-B (US ERDC)	141	--	--	--	11,964
	N2-CC	--	18.0	--	--	--
	N2-C	--	17.8	--	--	--
N3	N3-A	142	--	2080	2205	11,418
	N3-B	142	--	2040	2162	9,759
	N3-C	--	--	--	--	--
	N3-D	--	--	--	--	--
N4	N4-A	140	--	1930	2046	--
	N4-B	140	--	2190	2321	--
	N4-CC	--	19.0	--	--	--
	N4-C	141	--	2150	2279	--
	N4-0C	--	20.1	--	--	--
	N4-D	--	--	--	--	--
N5	N5-A	140	--	2420	2514	--
	N5-B	141	--	2200	2285	--
	N5-BB	--	18.7	--	--	--
	N5-0C	--	19.4	--	--	--
	N5-C	--	--	--	--	--
N6	N6-A	142	18.6	2110	2237	--
	N6-B	142	18.3	2140	2268	--
	N6-C	141	16.8	2230	2364	--
	N60-C	--	20.2	--	--	--
N2A	N2A-A	142	--	1900	2014	10905
	N2A-B	142	--	2080	2205	11399
	N2A-C	143	--	2190	2321	11642
N2B	N2B-A	141	--	2220	2353	12508
	N2B-B	140	--	1890	2003	10709
	N2B-C	139	--	1960	2078	11639
N2C	N2C-A	141	--	1770	1876	12564
	N2C-B	142	--	2060	2184	12095
N6A	N6A-A	145	--	2690	2851	13008
	N6A-B	145	--	2610	2767	12639
	N6A-C	143	--	2940	3116	12247
N6B	N6B-A	143	--	2500	2650	--
	N6B-B	143	--	2550	2703	--
	N6B-C	--	18.0	--	--	--
N6C	N6C-A	140	--	2030	2152	--
	N6C-B	142	--	2180	2311	--
	N6C-C	142	--	2130	2258	--
Number of Samples		**31**	**12**	**29**	**29**	**15**
Mean		**141.7**	**18.6**	**2208**	**2336**	**11,856**
Standard Deviation		**1.5**	**1.0**	**263.2**	**278.7**	**942.3**
Standard Error Mean		**0.26**	**0.29**	**48.9**	**51.7**	**--**
Lower 95 % Mean		**141.2**	**17.9**	**2108**	**2156**	**--**
Upper 95 % Mean		**142.2**	**19.2**	**2308**	**2515**	**--**

*A Correction factor (f_d) of 1.06 was applied to all core compressive strength measurements due to presumed damage due to coring. Inaddition a correction factor (F_{dia}) of 0.98 was applied to the 6 inch cores (core N2 and N5). Correction factors for *l/d* ratio ($F_{l/d}$) and moisture content (F_{mc}) were both 1.0 for all core section. $f_c = F_{l/d}F_{dia}F_{mc}F_d f_{core}$ per ACI 214-4R- Chapter 8.[12]

**Average of measurements taken at several locations along these core sections.

-- Indicates no data were collected.

4.2 Petrographic Evaluation

Two concrete core sections and a piece of overcore from the 221-H Personnel Tunnel north wall were characterized by the USACE ERDC to: (1) determine the ingredients in the concrete, (2) estimate the mix proportions, and (3) identify potential chemical degradation mechanisms by petrographic analysis.[14]

The concrete contained portland cement, schist coarse aggregate, quartz fine aggregate and a high capillary porosity which was interpreted as being due to a relatively high water to cement ratio, i.e., at least 0.5. The proportions of these ingredients were determined by two methods and are listed in Table 4-2. The concrete did not contain supplementary cementitious material such as fly ash. Small microcracks (~10 μm long) were ubiquitous throughout the samples examined and were attributed to shrinkage during curing. Some appeared to be infilled with secondary phases. Clay coated schist aggregates were observed in the north wall concrete cores.

Table 4-2. Estimates of north wall concrete mix proportions.[14]

Ingredient	Petrographic thin section estimate (vol. %)	ASTM C457 SEM point count estimate (vol. % range)
Coarse Aggregate	40	32 - 49
Fine Aggregate	40	20 - 30
Cement Paste	20	25 - 37
Air Voids	Not measured	1 - 7

No indications of chemical degradation were observed in the two clean north wall cores analyzed. Petrographic results are summarized below:

- Chemical Degradation
  - Portlandite, $Ca(OH)_2$ was detected in both core sections. Consequently, the pH of the concrete pore solution is alkaline (pH = 12.4), i.e., in equilibrium with $Ca(OH)_2$.
    - Rebar is passivated and corrosion is not expected to be a degradation mechanism.
  - Calcite was not detected in XRD patterns of the matrix from these core sections.
    - Carbonation is a form of acid attack which is ubiquitous for concrete exposed to air.
  - No evidence for alkali silica reaction was observed.
  - Sulfate attack was not observed.
  - No other phases or features associated with or resulting from chemical degradation were observed.

SRNL personnel evaluated the concrete alkalinity using a phenolphthalein dye test to estimate pH of the concrete sections. The alkalinity of all of the non-radioactive north wall core sections was greater than pH 10.2 except on the surface in the Personnel Tunnel. This result supports rebar passivation.

5.0 Results of Clean South Wall Core Sections

5.1 Mechanical and Physical Properties

Compressive strength, porosity, density, and UPV results for the clean sections of the 221-H Personnel Tunnel south wall cores are tabulated in Table 5-1. The 20 compressive strength measurements and were obtained from core sections that were collected from 6 locations in the south wall.

The mean value for the as measured/as reported data set is 24.9 MPa (3618 psi) and the standard deviation was 4.4 MPa (638 psi). The upper 95% mean value was 30 MPa (3916 psi) and the lower 95% mean value was 22.9 MPa (3319 psi). The mean value for the 20 measurements corrected for geometry and coring damage was 26.4 MPa (3835 psi) and the standard deviation was 4.7 MPa (676 psi). The upper 95 % mean value for the corrected compressive strength data was 28.6 MPa (4151 psi) and the lower 95% mean value was 24.3 MPa (3518 psi). The data set tested positive for a normal distribution.

Density (unit weight) was measured on 18 core sections from the south wall. The mean density was 2275 kg/m^3 (142 lbs/ft^3). The standard deviation was 35.2 kg/m^3 (2.2 lbs/ft^3). The data set tested positive for a normal distribution.

Porosity that transmits moisture as the result of wetting and drying was measured on 8 core sections from the south wall. The mean transmissive porosity volume was 17.4 volume percent. The standard deviation was 1.48 volume percent and the upper and lower 95% mean values were 18.6 and 16.2 volume percent, respectively. The data tested positive for a normal distribution.

Ultrasonic pulse velocity measurements were made on 7 core sections from the south wall. Multiple measurements were made on each core section and the average value for each core section is provided in Table 5-1. The mean value for these cores sections was 4644 m/s (15,237ft/s). The standard deviation was 180.7 m/s (593 ft/s) and the upper and lower 95% mean values were 4811and 4476 m/s (15,785 and 14,688 ft/s), respectively.

Microhardness measurements were also made on a section of core adjacent to compressive strength sample S2-BB. Microhardness results are provided in Table 5-2. The corrected compressive strength of core section S2-BB was 4039 psi. The mean value for these cores sections was 22.6 HV. The standard deviation was 4.5 HV and the upper and lower 95% mean values were 24.5 and 20.5 HV, respectively.

UPV data sheets are included in Appendix F. Compressive strength, density and porosity data sheets are included in Appendix G.

Table 5-1. Mechanical and physical properties non-radioactive concrete core sections from the 221-H Personnel Tunnel H-Canyon Exhaust Tunnel south wall.

Core Location	Core Section / Sample ID 221H-PT3-	As Reported Density (lbs/cft)	Porosity (vol. %)	Compressive Strength (psi)		UPV Average (ft/s)
				As Measured / Reported	Corrected for drilling damage**	
S1	S1-A	143	15	2150	2279	--
	S1-B	145	16.5	3380	3583	--
	S1-C	145	--	3800	4028	--
	S1-D (S1-Spare)	143	--	3640	3858	15297
S2	S2-A	--	18.6	--	--	--
	S2-B	--	--	2610*	2767	--
	S2-BB	142	--	3810	4039	--
	S2-C	142	17.7	3420	3625	--
	S2-D ERDC	--	--	--	--	15546
S3	S3-A	141	--	3310	3509	--
	S3-B	144	--	3900	4134	--
	S3-C	144	--	4540	4812	--
	S3-CC	--	16.1	--	--	--
	S3-D	--	--	--	--	15611
S4	S4-A	141	--	2960	3138	--
	S4-B	140	--	3710	3933	--
	S4-C	141	--	3960	4198	--
	S4-CC	--	19.2	--	--	14159
	S4-D	--	--	--	--	14724
S5	S5-A	138	--	3100	3286	--
	S5-B	140	--	3560	3774	--
	S5-C	140	--	3650	3869	---
	S5-CC	--	18.9	--	--	--
	S5-D	--	--	--	--	15448
S6	S6-A	138	--	3310	3509	--
	S6-B	144	--	4360	4622	--
	S6-C	144	--	4540	4812	--
	S6-CC	--	17.2	4640*	4918	--
	S-6D USERDC	--	--	--	--	15872
Number of Samples		**18**	**8**	**20**	**20**	**7**
Mean		**142**	**17.4**	**3618**	**3835**	**15237**
Standard Deviation		**2.2**	**1.48**	**638**	**676**	**593**
Standard Error Mean		**0.52**	**0.52**	**142.7**	**151.2**	**224.2**
Upper 95 % Mean		**143.0**	**18.6**	**3916**	**4151**	**15785**
Lower 95 % Mean		**140.8**	**16.2**	**3319**	**3518**	**14688**

*Values were corrected by CMLT for *l/d* correction factors. S-2A measured value, 2720 psi, was corrected as follows: 2720 psi x 0.96 = 2767 psi (reported). S6-D measured value, 4640 psi was corrected as follows: 4640 psi x 0.98 = 4918 psi (reported).

** A Correction factor (f_{core}) of 1.06 was applied to all core compressive strength measurements (f). All cores were made with 4-inch core barrels.

-- Indicates no data was collected

Table 5-2. Microhardness measurements for the south wall core sections approximately 305 mm (12 inches) from Personnel Tunnel.

Core Section ID	Hardness (HV)
S-2-BB	24.3
	21.6
	18.7
	20.2
	23.2
	25.5
	18.9
	25.5
	16.7
	29.9
	30.4
	14.6
	24.7
	21.9
	14.7
	20
	26.1
	24.2
	29.6
	21.2
	22.6
Number of Samples	**21**
Mean	**22.6**
Standard Deviation	**4.5**
Standard Error Mean	**0.97**
Upper 95 % Mean	**24.5**
Lower 95 % Mean	**20.5**

5.2 Petrographic Evaluation

Two concrete core sections from the 221-H Personnel Tunnel south wall were characterized by the USACE ERDC to: (1) determine the ingredients in the concrete, (2) estimate the mix proportions, and (3) identify potential chemical degradation mechanisms by petrographic analysis.[14]

The concrete contained portland cement, schist coarse aggregate, quartz fine aggregate, and a high capillary porosity which was interpreted as being due to a relatively high water to cement ratio, i.e., at least 0.5. The proportions and ingredients were determined by two methods and are listed in Table 5-3. The concrete did not contain supplementary cementitious material such as fly ash. Small microcracks (~10 µm long) were ubiquitous throughout the concrete and were most likely due to early age shrinkage. Some cracks appeared to be infilled with secondary phases.

Table 5-3. Estimates of south wall concrete mix proportions.[14]

Ingredient	Petrographic thin section estimate (vol. %)	ASTM C457 SEM point count estimate (vol. % range)
Coarse Aggregate	40	36 - 50
Fine Aggregate	40	21 - 26
Cement Paste	20	25 - 35
Air Voids	Not measured	3.2 - 3.4

No indications of chemical degradation were observed in the two clean south wall cores analyzed. Petrographic results are summarized below:

- Chemical Degradation
  - Portlandite, $Ca(OH)_2$ was detected in both core sections. Consequently, the pH of the concrete pore solution is alkaline (pH = 12.4), i.e., in equilibrium with $Ca(OH)_2$.
    - Rebar is passivated and corrosion is not expected to be a degradation mechanism.
  - Calcite was not detected in XRD patterns of the matrix from these core sections.
    - Carbonation is a form of acid attack which is ubiquitous for concrete exposed to air.
  - No evidence for alkali silica reaction was observed.
  - Sulfate attack was not observed.
  - No other phases or features associated with or resulting from chemical degradation were observed.

6.0 Discussion

The characterization approach was focused to evaluate material properties for both clean and radiologically contaminated concrete cores recovered from the 221-H Section 3 Personnel Tunnel. The south wall and north wall cores were examined to: (1) provide current concrete physical and mechanical properties (clean samples) and (2) effects of 60+ years of aging in a passive environment (clean samples) as compared to exposure to the corrosive canyon exhaust environment (radioactive samples). The characterization plan was constructed with the assumption that chemical, mineralogical, and mechanical gradients were present in the concrete exposed to the canyon exhaust. This gradient concept is expressed as an affected zone with the most altered material directly in contact with the canyon exhaust. See Figure 6-1. Mechanical properties (such as compressive strength) were not directly measured (ASTM C39) on the concrete core sections exposed to the canyon exhaust because they were assumed to vary as a function of distance from the exposed surface. The depth of the affected zone and the nature and degree of alteration were unknown at the time this study was initiated and could not be derived based on tunnel inspections and surveillance activities.

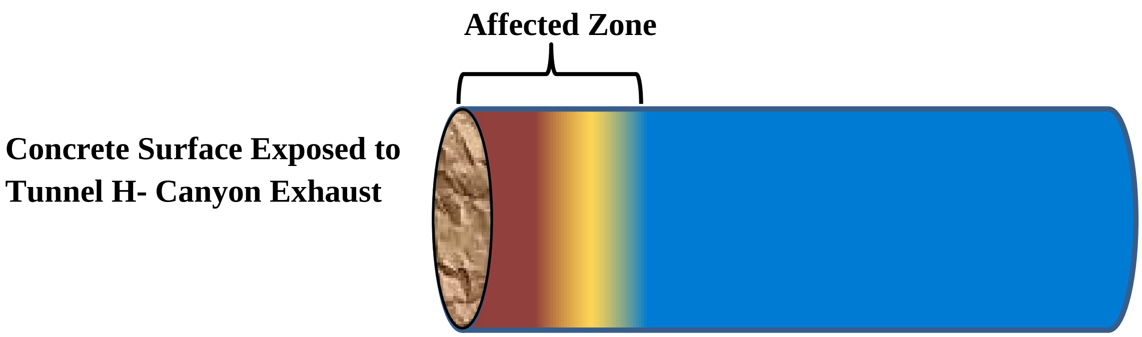


Figure 6.1. Conceptual Concrete Core Suspected Affected Zone Location to Tunnel Surface. (not to scale)

6.1 North and South Wall Mechanical and Physical Properties: Direct Measurements

A statistical analysis of the clean north and south wall compressive strength measurements indicated that (1) results for each wall pass the test for a normal distribution and (2) the results from each wall represent different populations. This is illustrated in Figures 6-2 to 6-4 by various statistical representations of the means, variances and scatter in the data.

The mean compressive strength corrected for coring damage and dimensional variations for 29 core sections from the north wall was 16.1 MPa (2336 psi). This is slightly below the design strength of 17.2 MPa (2500 psi). The mean corrected compressive strength for 20 core sections collected from the south wall was 26.4 MPa (3835 psi) which is well above the design strength of 17.2 MPa (2500 psi). ERDC concluded that both walls were constructed of concrete with fairly similar mix proportions except that the north wall concrete had a higher in air content and possibly a higher water to cement ratio than the south wall concrete.

ERDC did detect extensive capillary porosity, especially in the north wall clean samples which they interpreted as indicating that the water to cement ratio in the north wall concrete was probably higher than that in the south wall concrete. This conclusion was corroborated by the higher non-evaporable water loss of the cement paste fraction for the south wall concrete compared to that for the north wall concrete, i.e., 18.5 mass percent compared to 21.4 mass percent, respectively.[14]

ERDC personnel observed small amounts of illite and kaolinite clay in petrographic samples coating some of the coarse aggregates in the north wall clean samples. ERDC postulated that the clay coatings resulted in poor adhesion between the aggregate and paste and concluded that this condition along with the high capillary porosity and high air content were the likely "culprits" responsible for the lower north wall compressive strengths.[14]

The densities (as received unit weights) and transmissive porosities for the north and south wall concrete samples were similar. The unit weights were typical, about 2275 kg/m^3 (142 lbs/ft^3), of concrete containing schist and quartz aggregates. The average transmissive porosities for both walls were high, 17 (south wall) and 19 (north wall) volume percent. These high concrete porosities support the ERDC conclusion, high water to cement ratios of at least 0.5 and a higher water to cement ratio for the north wall concrete mix.

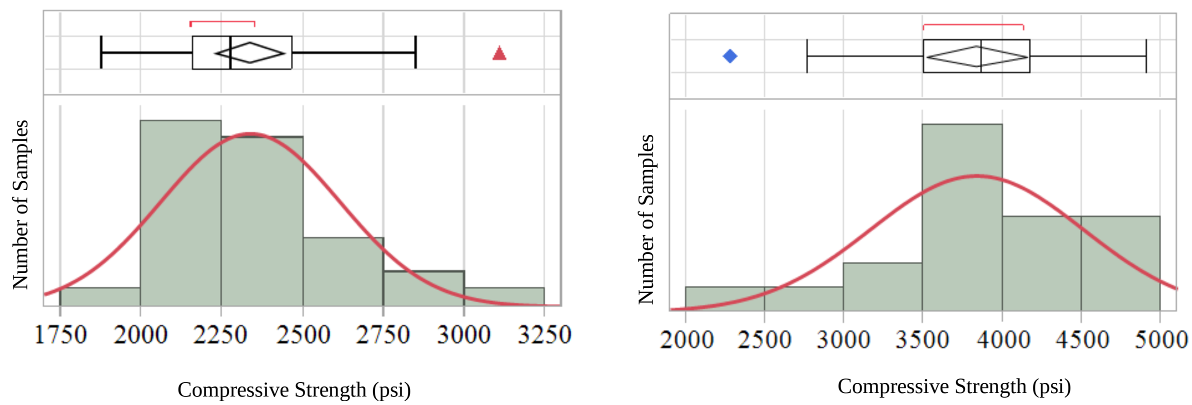


Figure 6.2. Normal distributions 221-H personnel corridor north (left) and south wall (right) concrete samples compressive strength (corrected for coring damage and dimensional variability).

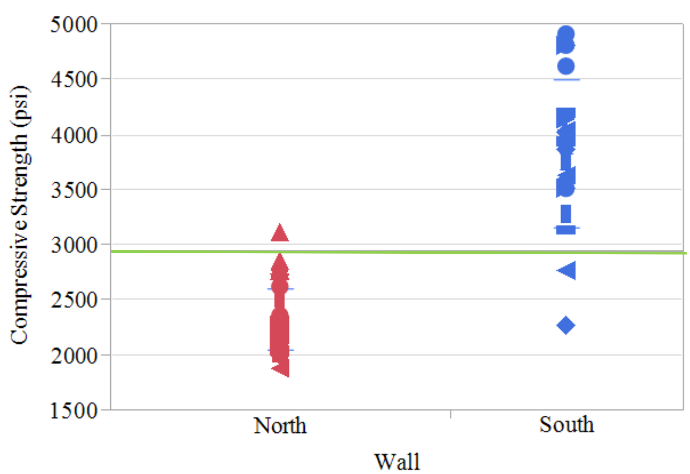


Figure 6.3. North and south wall compressive strength results relative to the average of the mean of the north plus south wall values. Green line = average of all measurements.

ERDC and SRNL did not observe any physical or chemical degradation by direct observation or the petrographic evaluation of the non-radioactive cores collected from Section 3 of the 221-H Personnel Tunnel. No indication of alkali silica reaction or cracking due to any other expansive reaction was observed. ERDC attributed microcracks in the clean cores to initial shrinkage during early age curing and attributed this cracking to a high water to cement ratio in the fresh concrete.

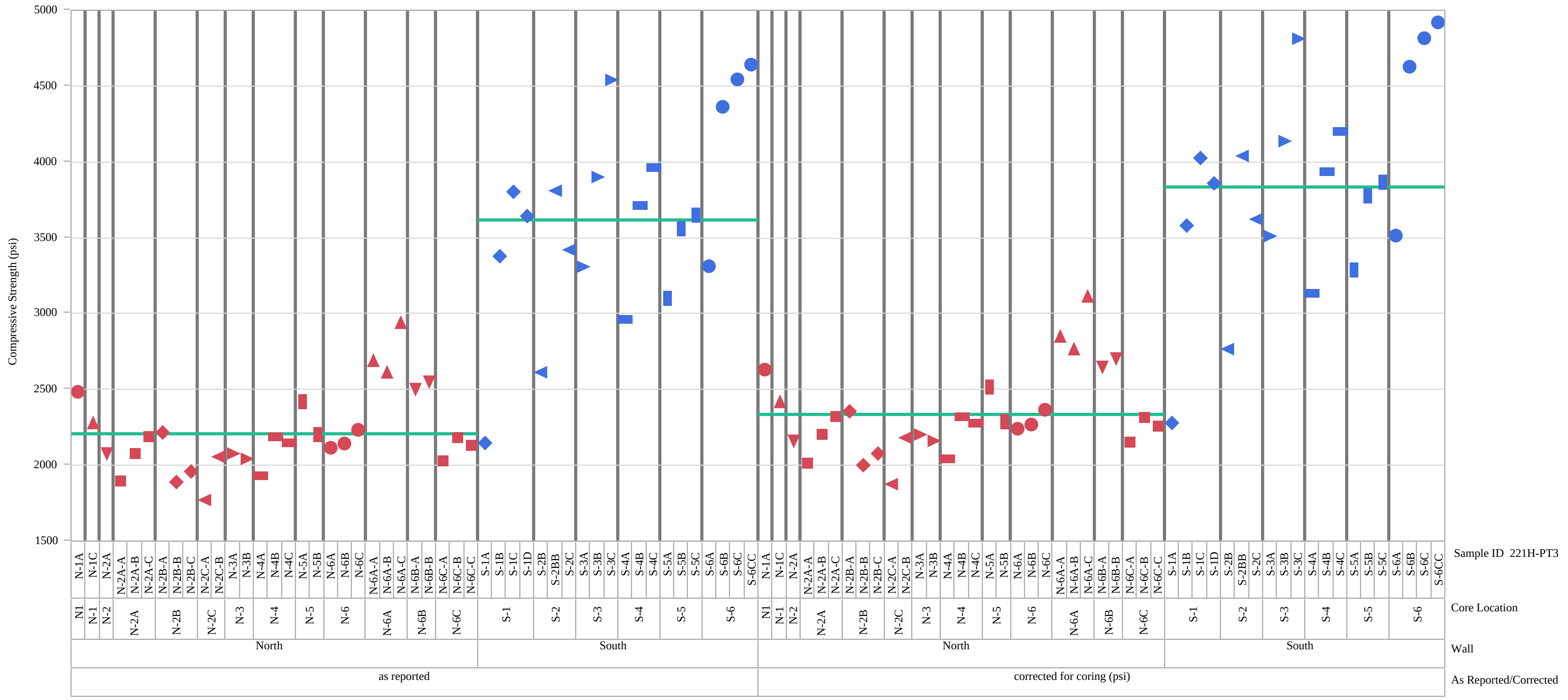


Figure 6.4. Variability chart for compressive strength measurements

Colors denote the wall of origin of the core (red=north, blue=south); Symbols refer to subsets of data from individual cores (●= Cores N-1, N-6 and S-6, ▲ = Cores N-1 and N-6A, ▼= Cores N-2 and N-6B, ■ = Cores N-2A and N-6C, ◆ = Cores N-2B and S-1, ◀ = Cores N-2C and S-2, ▶ = Cores N-3 and S-3, ▬= Cores N-4 and S-4, ▮= Cores N-5 and S-5). Green lines indicate average values.

6.2 North and South Wall Mechanical and Physical Properties: Indirect Measurements

6.2.1 Interpretation of UPV Results

UPV values are related to the elastic modulus of the concrete which is a function of material properties such as porosity (micro and macro), defects (cracks), density (bulk and phase), moisture saturation, and microstructure.[17-22] UPV measurements were made on the north wall radiological samples as a function of distance from the surface exposed to the canyon exhaust using the same techniques as used on the clean cores (radial measurements across the core diameter). Compression tests were not performed on the radiological cores sections.

Statistical analyses of the UPV data collected from 5 different north wall radiological cores were compiled as a function of distance from the exposed surface and plotted in Figure 6.5. The depth-discrete data were compared to all of the measurements collected from clean core sections which were grouped and assigned a single depth from the exposed surface of 18 inches. The depth-discrete mean values suggest a decline in the velocities as a function of distance from the surface exposed to the canyon exhaust. One possible explanation is that this is a result of a decrease in density as a function of increasing distance from the surface. Secondary mineralization of the matrix – calcite replacement of portlandite in the affected region could be responsible for the higher density near the surface compared to the density of the unaffected concrete.

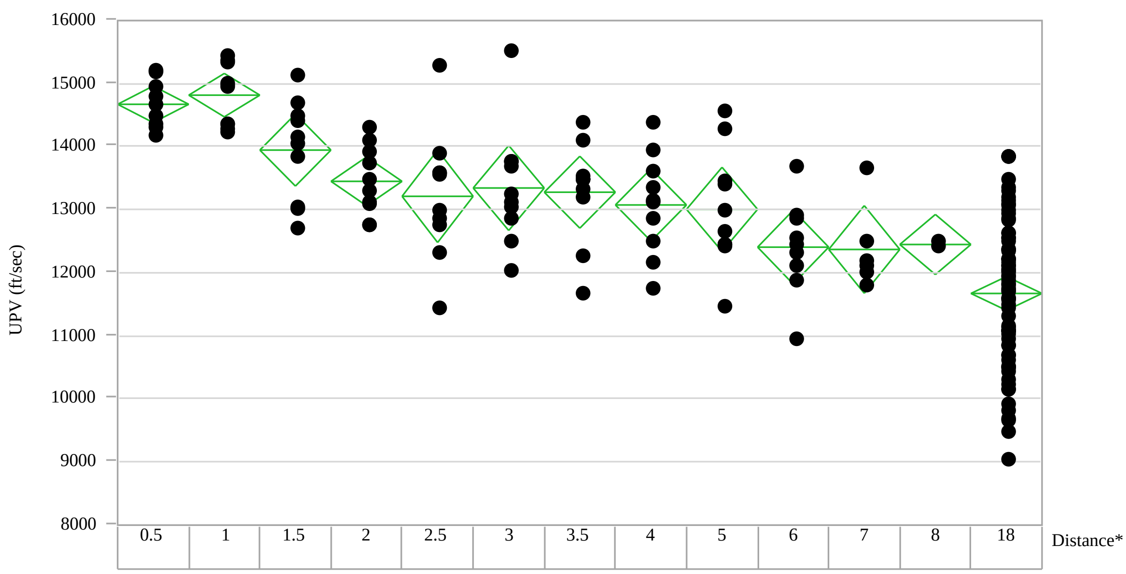


Figure 6.5. All north wall UPV measurements as a function of distance from the exposed surface (14671 ft./s > UPV_{avg} > 11673 ft./s).

6.2.2 Correlation of UPV and Compressive Strength Results

The possibility of using the UPV data to predict compressive strength of the radiological core sections affected by canyon exhaust was evaluated using the following approach. A subset of results was compiled from the clean core sections. This subset consisted of both UPV and compressive strength measurements made on thirteen clean cores from the north wall and 1 core from the south wall. See Table 6-1. The compressive strengths were plotted against the averaged UPV measurements for each core section and a trend line was fitted to the data using the polynomial equation shown in Figure 6-6.

Table 6-1. Comparison of compressive strength and UPV measurements made on individual core sections.

Core ID	Compressive Strength (psi)	Average UPV (ft./s)	Compressive Strength (MPa)	Average UPV (m/s)
S1-D (S1-Spare)*	3858	15297	26.4	4662.5
N3-A**	2205	11,418	15.2	3480.2
N3-B	2162	9,759	14.9	2974.5
N2A-A	2014	10905	13.9	3323.8
N2A-B	2205	11399	15.2	3474.4
N2A-C	2321	11642	16.0	3548.4
N2B-A	2353	12508	16.2	3812.4
N2B-B	2003	10709	13.8	3264.1
N2B-C	2078	11639	14.3	3547.5
N2C-A	1876	12564	12.9	3829.5
N2C-B	2184	12095	15.1	3686.6
N6A-A	2851	13008	19.7	3964.8
N6A-B	2767	12639	19.1	3852.4
N6A-C	3116	12247	21.5	3732.9
Average Values	2428	11,988	16.7	3653.9

*S wall core data from Table 5-1.
**All N core data from Table 6-1.

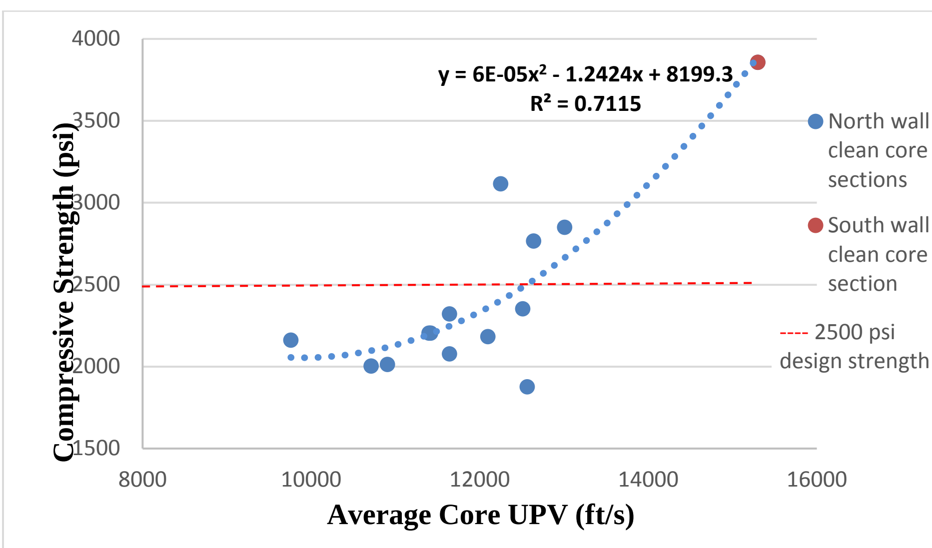


Figure 6-6. North and south wall UPV measurements for concrete cylinders plotted against the compressive strength of each cylinder (13 from the north wall and 1 from the south wall. (Data were taken from Tables 4-1 and 5-1, respectively.)

The trend line was used to predict compressive strengths and a function of the depth discrete UPV measurements made on the radiological core sections. The predicted strengths are listed in Table 6-2 and plotted in Figure 6-7. Two other properties of these core sections that exhibited depth-discrete trends, leachable nitrate and the presence $Ca(OH)_2$ in the matrix are summarized in Table 6-2 and Figure 6-7.

Because matrix chemistry and mineralogy were shown to vary as a function of distance from the exposed surface and are known to affect porosity, density and UPV values, the attempt to relate UPV measurements to compressive strength of the radiological core sections did not result in a defensible correlation between these two properties. The core sections exposed to the canyon exhaust clearly showed inherent differences in the concrete chemistry and mineralogy which may or may not influence mechanical properties of these cores. Consequently, the affected regions of the cores may have higher or lower or the same mechanical properties as the unaffected concrete in the north wall. Currently, characterization results are insufficient to determine a residual strength value for the portion of the north wall affected by exposure to the canyon exhaust.

Table 6-2. Depth-discrete compressive strength values for a composite north wall exposed core section calculated using the UPV-compressive strength relationship in Figure 6-5.

Distance from surface exposed to canyon exhaust (inches)	Average UPV from Table 3-4 (ft./s)	Predicted compressive strength from trend line in Figure 6-6 (psi)	Nitrate Leachate Concentration (mg/L)	Presence of Portlandite and Calcite in Matrix
0.125	--	--	2175	Calcite No Portlandite
0.375	--	--	2445	
0.5	14817	2963	--	
0625	--	--	3660	
0.875	--	--	2450	
1	14672	2887	--	
1.25	--	--	2830	
1.5	13946	2542	--	
1.625	--	--	1235	
2	13451	2344	980	
2.25	--	--	400	Calcite Portlandite in Core N3-D
2.5	13345	2305	--	
3	13278	2281	--	
3.5	13213	2258	--	
4	13076	2213	149	
5	13007	2190	22.5	
6	12450	2032	10	Portlandite in all cores samples Calcite
7	12407	2021	10	
8	12371	2012	--	
9	--	--	22.7	

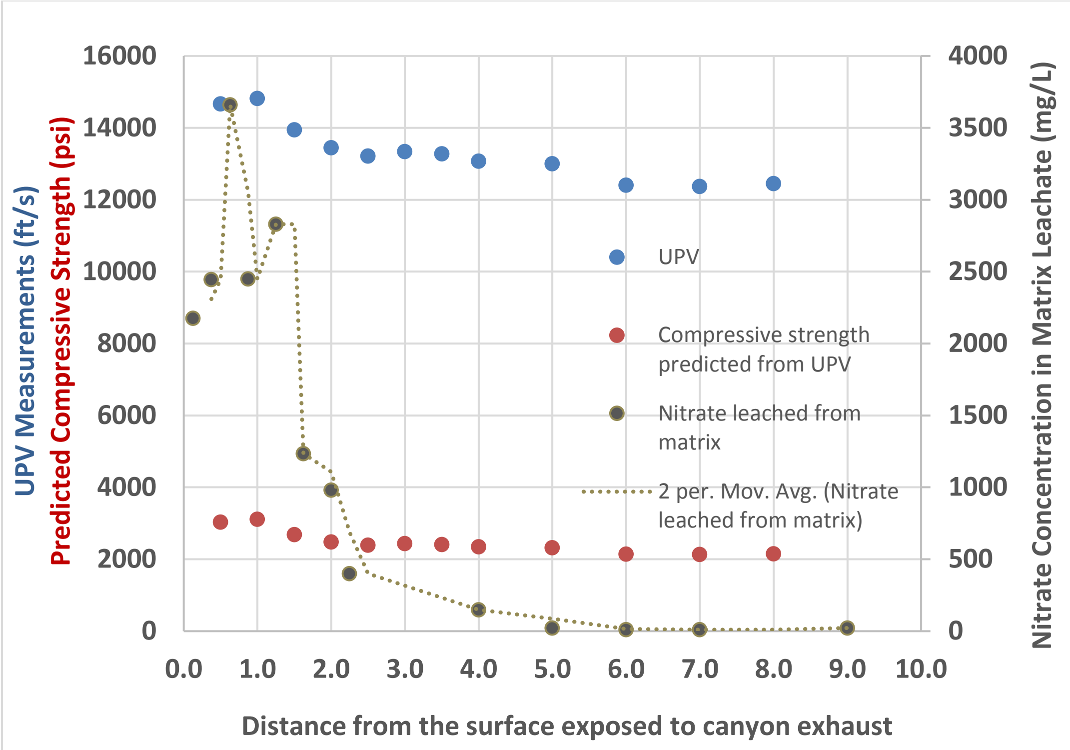


Figure 6-7. Comparison of averaged depth-discrete UPV data and averaged leachable nitrate concentrations to predicted compressive strength values as a function of distance from the surface exposed to canyon exhaust.

6.2.3 Interpretation of Microhardness Results

The intent of the microhardness measurements was to evaluate the (1) sensitivity of microhardness measurements to other concrete properties (2) difference in matrix integrity as a function of distance from the exposed surfaces of the radiological core sections.

Based on published literature, microhardness results for cement paste and concrete have been shown to vary due to matrix mineralogy, porosity or microstructural evolution.[18-20] Variations within individual sample sets have also been attributed to environmental factors, sample preparation, carbonation, and/or proximity to aggregates.[19, 20]

Microhardness measurements from the north and south wall concrete cores are shown in Figure 6-8. Differences between north and south wall microhardness measurements were not as apparent as the differences in the north and south wall UPV and compressive strength measurements. Some differences between north wall and south wall cores may be inferred. Specifically, the scatter from south wall data is less and the average value for south wall is slightly lower (22.6 ± 4.6 HV) than that of the north wall (27.6 ± 10 HV). Three possible explanations for the lower scatter in the south wall results are (1) higher matrix integrity in the south wall corresponding to higher compressive strength and/or (2) fewer number of cores evaluated (3) differences in matrix mineralogy between the concrete exposed to canyon exhaust and concrete from the interior of the south wall. The north wall microhardness data from four cores exposed to the canyon exhaust were averaged as a function of distance from the exposed surface in Figure 6-9. Statistical analysis showed that average microhardness value of the matrix phase is unchanged as depth from the surface exposed to the canyon exhaust.

In the north wall radiological core sections, depth-discrete mineralogy analysis indicated that the original cement matrix phases have been chemically altered by the canyon exhaust. These reaction products have been shown to coexist with typical hydrated portland cement phases present in unaffected portions of the north wall concrete and did not result in detectable changes in matrix microhardness.

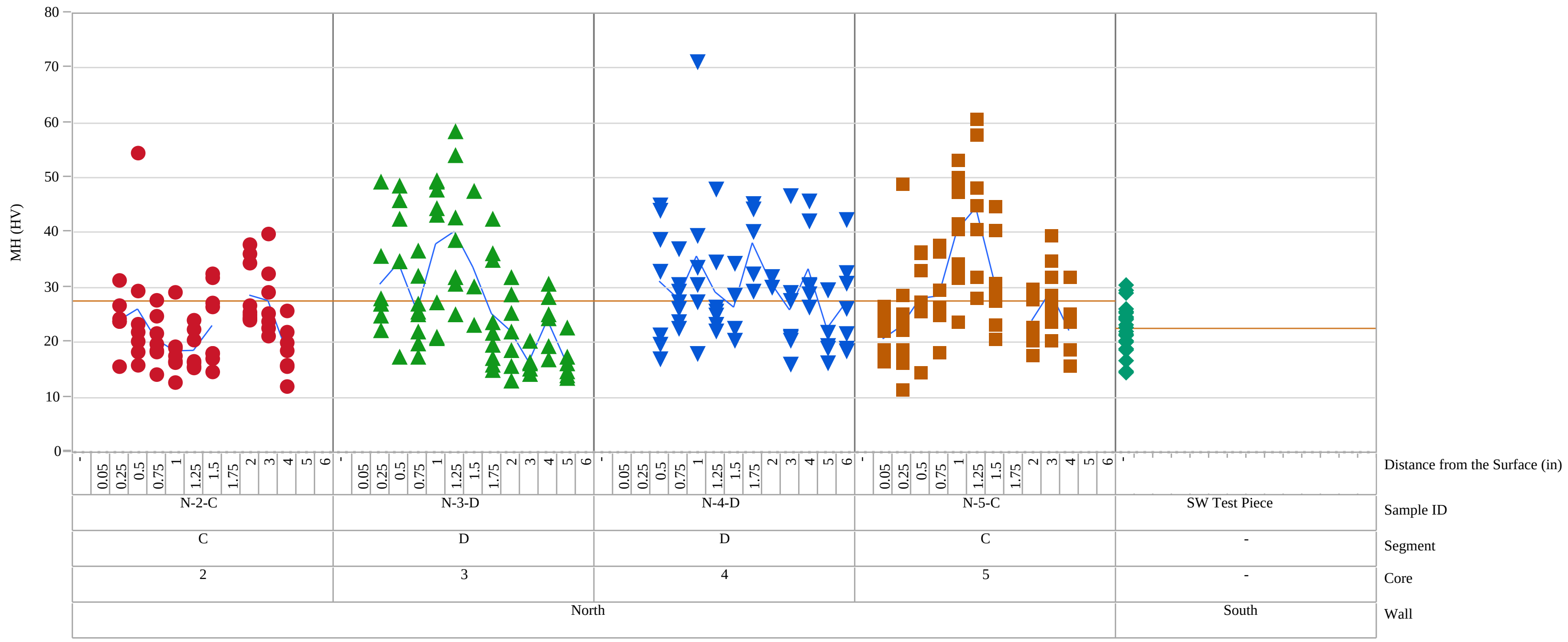


Figure 6.8. North and south wall microhardness comparison. Reported Mean for data sets are 27.6 (north wall) and 22.6 (south wall)

Colored symbols denote the core from which measurements were taken (● = N-2-C, ▲ = N-3-D, ▼ = N-4-D; ■ = N-5-C)
Distance from surface denotes the approximate distance in inches from the surface exposed to tunnel environment.

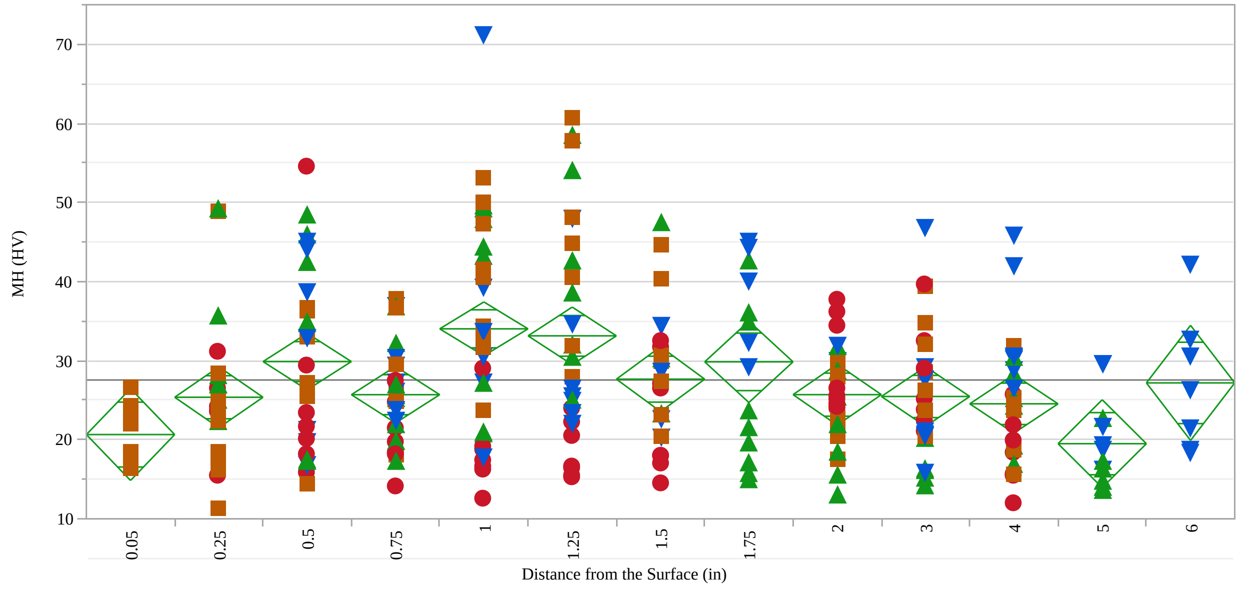


Figure 6.9. All north wall microhardness measurements as a function of distance from the exposed surface (HV_{avg} of 27.6)

Colored symbols denote the core (● = N-2-C, ▲ = N-3-D, ▼ = N-4-D; ■ = N-5-C).

6.3 Degradation / Alteration of 221-H Personnel Tunnel the North and South Wall Concrete

ERDC did not observe any degradation of the clean portions of Section 3 of the 221-H Personnel Tunnel north and south walls. ERDC performed petrographic analyses on two clean cores and a piece of over core collected from the north wall and two clean core sections collected from the south wall. They determined that the concrete had not been subjected to deleterious chemical alteration or reactions, such as sulfate attack or ASR, and the clean concrete samples did not show carbonation.[14] Therefore, ERDC concluded that the "clean" concrete in both walls is not expected to lose strength in the future.[14] ERDC also recommended continued monitoring of the degraded north wall concrete exposed to the canyon exhaust (interior walls of the Cross-over Tunnel and Exhaust Tunnel).

Degradation of the north wall concrete exposed to the H-Canyon exhaust over 60+ years has been previously documented.[8] Recent photographs of the surface were obtained as part of the 2016-2017 coring and inspection effort and show exposed rebar and angular aggregates protruding from the walls. Debris from the walls has accumulated on the floor of the tunnel and on a duct in the tunnel.

Two field measurements in 2017 through core borings through the wall that separates Section 3 of the 221-H Personnel Tunnel and Cross-over Tunnel indicated that the north wall thickness is 0.86 m (33.75 inches) and 0.87 m (34.25 inches) on the west and east ends, respectively. These measurements are less than the design thickness of 0.9 m (36 inches). The loss of thickness is presumed to be the result of erosional loss resulting from 60+ years of H-Canyon operation. Despite this, exposed aggregate on the tunnel surfaces does not appear loose nor does the wall surface appear to be powdery or crumbling. The protruding/exposed aggregates are firmly fixed in the concrete matrix.[8]

The primary factors responsible for the observed degradation were identified as nitric acid and wind erosion (48 to 64 km/h (30 to 40 mph air stream). Concurrent nitric acid dissolution of portlandite, $Ca(OH)_2$ and exposure to atmospheric CO_2, resulted in secondary matrix mineralization, i.e., formation of calcite in the matrix of affected portions of the concrete to the canyon exhaust. This interpretation is supported by the petrographic and mineralogical results.

The absence of portlandite, $Ca(OH)_2$ and presence of calcite, $CaCO_3$, is evidence of reaction of atmospheric CO_2 with water to form bicarbonate HCO_3^- which reacted with portlandite to form calcite as a secondary matrix phase. Portlandite was absent from the matrix phase assemblages of cores N1-D, N2-C, N-4-D, and N-5-C between the surface and about 76 mm (3 inches). Portlandite was present in N3-D at the matrix collected between 51 and 64 mm (2 and 2.5 inches). The extent of CO_2 / bicarbonate ion penetration and carbonation in the north wall is unclear because calcite or a $CaCO_3$ polymorph appears throughout the entire 228 mm (9 inch) length of the radioactive north wall core sections. A discrete calcite surface was not observed on the expose surfaces of the radiological cores, and compete carbonation of the hydrated alkaline cement matrix phases was not observed in any of the five cores examined. This feature was attributed to the high porosity of the concrete which facilitated penetration of CO_2 into the bulk material rather than intense localized conversion on the surface.

Nitrate was detected in leachates from pulverized matrix material collected from two cores (N4-D and N5-C). The concentrations were reported as a function of distance from the surface exposed to the canyon exhaust (Figure 3.6). Relatively high concentrations of nitrate (1000 to 3800 µg/mL) were extracted from N-4-D and N-5-C matrix sub-samples collected between 0 and about 51mm (2 inches). See Table 3-8. Lower concentrations of nitrate (1000 to150 µg/mL) were extracted from subsamples about 2 to 4 inches from the exposed surface. Very low concentrations of nitrate (22.5 to 10 µg/mL) were detected to depths beyond 102 mm (4 inches) in these cores (Table 3-8).

The most nitrate-rich portions of these cores correspond to the regions with higher UPV velocities (about 10 % higher) and roughly correspond to the darker colored regions observed on the as-received radioactive core sections. The darker surface regions were initially referred to as the “affected zones”. See Figure 6-1.

SEM and XCT imaging and x-ray diffraction analyses of the radioactive north wall core sections did not indicate sulfate attack or cracking from any other expansive reaction. However, a few features in core N5-C physically resembled gel formed by ASR. These features were only present in the near surface region (0 to 500 µm) and did not have chemical signatures indicative of ASR gel. Other unidentified features (Figure 3.21) were observed in N5-C and were attributed to artifacts of sample preparation.

The surface of each of the three cores examined by SEM-EDS was unique. The surface of N3-D was characterized by at least two layers with similar elemental signatures but different textures. Each layer was about 200 µm thick (Figure 3-13). A discrete multiphase layer about 50 µm thick was observed on portions of the surface of core N4-D. (Figure 3.17). No layering was observed on Core N5-C.

Based on the results presented in this report, mechanical properties, i.e., compressive strength or residual compressive strength values cannot be assigned to the “affected” region. However, XCT imaging indicated material continuity in the N3-D and N4-D core profiles over their entire length which included the exposed surface, affected region, and unaffected material (6-9 inches from the surface). No obvious changes/gradients in density or porosity and no internal macrocracking or delamination were observed. See Figure 3-7 and 3-8.

6.4 Effects of H-Canyon Exhaust on Cross-over Tunnel Concrete

The H-Canyon Cross-over Tunnel is constructed of reinforced concrete with a design strength of 17.2 MPa (2500 psi). The design thickness of the Cross-over Tunnel south wall was 0.91 m (36 inches). The mean strength of 29 core sections collected from the wall in 2017 was 2336 psi, and the standard deviation was 1.9 MPa (279 psi). The tunnel was initially painted and remote inspections indicated that the concrete was protected until the early 1970s. The exposure environment has been somewhat variable because the exhaust composition has varied over the 60+ years of operation.

Measurements made during the 2017 coring activity indicated the current north wall thickness, measured through the core holes, was 0.86 m (33 ¾ inches) at the west end and 0.87 m (34 ¼ inches) at the east end of the tunnel. A 9.1 m (30-foot) section of the Cross-over Tunnel south wall has exposed vertical rebars as well as some exposed horizontal rebar.[23] This indicates that about 57 mm (2.25 inches) of concrete cover has been lost over limited portions of the Cross-over tunnel. The decrease in the wall thickness is the result of a combination of exposure to nitric oxide (NO) vapors and erosion by the high velocity exhaust flow through the tunnel (30 to 40 mph) over 60+ years of operation. Concrete debris consisting of gravel, sand, and matrix particulates has accumulated on the tunnel floor and along the sides of the walls. Some surfaces show more material loss than other areas as would be expected in a dynamic environment. A sketch of the various features observed in the H-Canyon tunnel are shown in Figure 6-10.

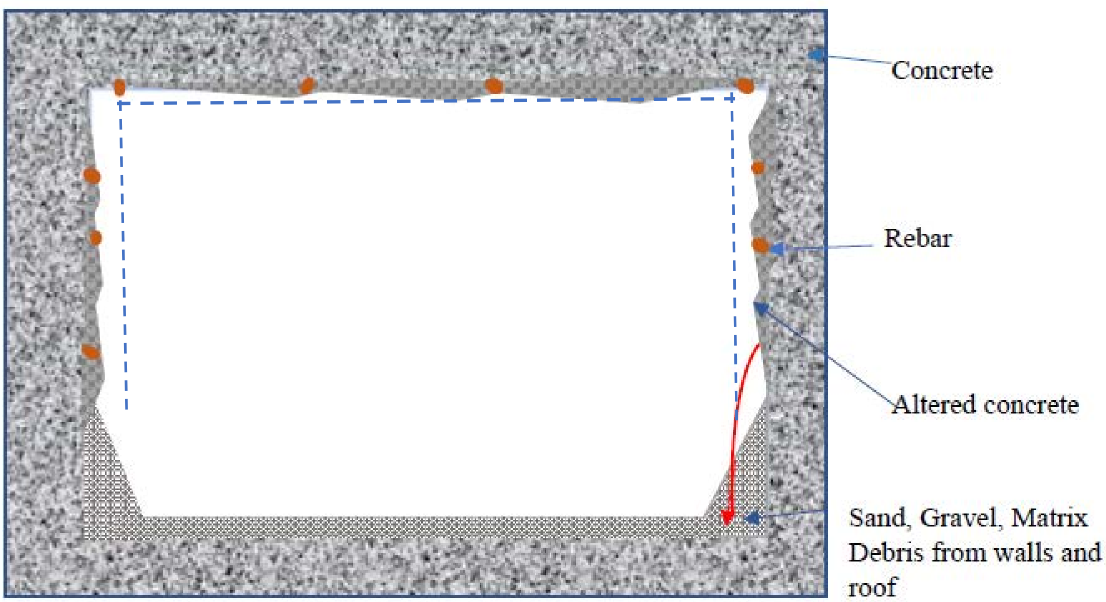


Figure 6.10. Sketch of cross over tunnel cross section illustrating current features. (Dashed line indicates original painted concrete surface. Not to Scale.)

Characterization to date indicates that nitric oxide and carbon dioxide in the exhaust air stream concurrently reacted with moisture in the tunnel and in the concrete to form nitric acid and bicarbonate ion which in turn reacted with the matrix phases in the concrete.

$4NO_2 + O_2 + 2H_2O = 4HNO_3$

$CO_2 + H_2O = H_2CO_3 + OH^- = HCO_3^-{}_{(aqueous)} + H_2O$ in alkaline concrete pore solution

Based on the current phase assemblages in the core sections exposed to the canyon exhaust air stream, these acids reacted with alkaline phases in the concrete matrix, i.e., the hydrated alkaline portland cement phases. Both nitric acid and bicarbonate ion preferentially react with alkali hydroxides and calcium hydroxide, $Ca(OH)_2$, and to a lesser extent with other calcium minerals present in the cement matrix. Exposure of the unprotected concrete (paint lost by early 1970s presumably by the due to erosion and chemical exposure) resulted in the following chemical reactions:

Nitric acid attack: $2HNO_3 + Ca(OH)_2 = Ca^{2+}_{(aqueous)} + 2NO_3^-{}_{(aqueous)} + 2H_2O = Ca(NO_3)_{2(soluble)} + 2H_2O$

Carbonation: $Ca^{2+}_{(aqueous)} + 2(OH)^-_{(aqueous)} + CO_2 = CaCO_{3\ (solid)} + H_2O$

and

$Ca^{2+}_{(aqueous)} + HCO_3^-{}_{(aqueous).} = CaCO_{3\ (solid)}$

Nitric acid attack and carbonation also resulted in progressive decalcification of the C-S-H phases and carbonation of the calcium aluminum sulfate hydrates

Because the solubility of calcium nitrate in water is very high, about 1212 g/L (at 20 °C), calcium ions were available to react with bicarbonate ion to form calcite which has a solubility about 3 orders of magnitude lower than that of calcium hydroxide, about 1.73 g/L (at 20 °C). The presence of calcite in the matrix was documented as a secondary cementing phase. Calcite is intimately intermixed with portlandite, C-S-H, calcium aluminum monosulfate (AFm), ettringite (AFt) and hydrogarnet phases. Calcite and the solid phases in hydrated portland cement are also susceptible to dissolution by nitric acid but much less so than calcium hydroxide. Based on petrography and x-ray diffraction results, partial decalcification of the C-S-H poorly ordered matrix phase and carbonation of the calcium aluminum monosulfate phase have also occurred. The phase alteration profiles are gradational and irregular and are influenced by the large angular aggregates in the concrete.

Thin (few tenths of a mm) carbonated sulfate-rich material which had several forms ranging from discrete discontinuous layers to continuous porous layers were observed on the surfaces of the cores which were exposed to the canyon exhaust. Physical erosion of these thin layers by the canyon exhaust air stream was presumed to result in progressive matrix loss and wall thinning. These features are illustrated in Figure 6-11.

The concrete aggregates are composed of silica minerals which are much more resistant nitric acid or bicarbonate ion than the calcium rich alkaline hydrates in the cement matrix. The schist gravel and quartz sand, did not appear to be affected by the canyon exhaust air stream expect that the aggregates exposed on the surface appeared polished or varnished. This was attributed to the high velocity air flow but a chemical effect or coating cannot be eliminated because it was not specifically investigated.

Characteristics observed in the five exposed core sections were grouped into those that were depth-dependent and those that were depth-independent summarized in Figure 6-11. Although compressive strength was not directly measured on the radiologically contaminated cores characterized in this study, properties relevant to residual strength were evaluated. Cracking, delamination, paste/aggregate de-bonding and rebar corrosion were not observed in the radiological core sections. Based on the field alkalinity test (pH >10.2) and presence of C-S-H and other alkaline phases in the matrix (pH >11), sufficient rebar passivation is provided such that its function is maintained and concrete cover is present.

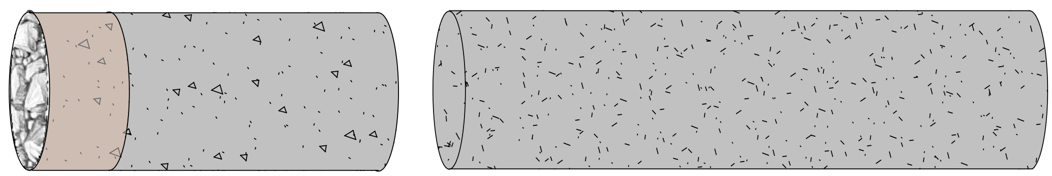
Rad concrete cores (8-9 inches)

Cored April to May 2017

Non-rad concrete cores (~24 inches)

Cored December 2016 to January 2017

Concrete Surface Exposed to Tunnel H-Canyon Exhaust



Carbonated sulfate-rich layers on exposed core surfaces ~ 0.1 to 0.2 mm thick

Rad Core Section

Physical Observations

- Darker color (gray brown) between 0 and ~64 mm (2.5 in.)
- Core N1-D dark brown zone (0 to ~89 mm) was atypical
- UPV faster between 0 and ~ 64 mm (2.5 in.) from surface
- No macrocracking
- No delamination parallel to the exposed surface
- Paste-aggregate bonding intact
- Capillary porosity and drying shrinkage cracking were similar to rad cores

Matrix Mineralogy Gradients: Rad Cores

- Thin mineralized layer ~ 0.1 to 0.2 mm thick on exposed surface
- Portlandite completely converted to calcite between 0 and ~ 51 mm (2 in.) and partially converted between ~ 51 and 127 mm (2 and 5 in.) from the exposed surface
- Decreasing calcite and increasing portlandite gradients between ~ 51 and 229 mm (2 and 9 in.)
- High nitrate between 0 and ~ 51 mm (2 in.)
- Moderate nitrate between ~ 51 and 127 mm (2 and 5 in.)
- Decalcification of C-S- H decreased from 0 to about 127 mm (5 in.)
- Alkalinity at least 10.2 over entire exposed core length

Chemical Degradation Gradients:

- Nitric acid attack (nitrate gradient)
- Carbonation (calcite gradient)
- No expansive reactions
- No indication of ASR, sulfate attack, or rebar corrosion

Bulk Core Sections (non rad)

Matrix Mineralogy Bulk Concrete:

- Portlandite, C-S-H, AFm, AFt, hydrogarnet
- pH > 10.2 to ~12.4 in equilibrium with $Ca(OH)_2$

Compressive strength:

- 2336 psi (average of 29 cores)

Chemical degradation / disruptive expansion

- No alkali silica reaction (ASR)
- No sulfate attack
- No rebar corrosion

Physical Observations:

- Capillary porosity and drying shrinkage cracking consistent with mix design
- No macrocracking
- No delamination
- Paste-aggregate bonding consistent with mix design and initial condition

Figure 6-11. Summary of features observed in the radiological concrete core sections that supports concurrent alteration reactions – nitric acid and carbonate matrix conversion to calcium nitrate and calcium carbonate.

7.0 Conclusions

This report provides a summary of characterization results for the concrete cores collected from the north and south walls of the 221-H Section 3 Personnel Tunnel during 2016 and 2017. The goal was to (1) support the H-Area Canyon Exhaust (CAEX) Soil and Concrete Core Sampling and Analysis effort; (2) characterize the effects and depth of affected concrete exposed to the canyon exhaust environment; and (3) collect additional physical property data on 1950's concrete. The results of this characterization will be used to refine input parameters to the 2014 H-Area CAEX Tunnel Seismic Qualification Calculations.[1]

Eighteen (18) concrete cores, twelve from the north wall and six from the south wall, were harvested from the 221-H Section 3 of the Personnel Tunnel. Sections from these clean cores were tested by the SRS Construction Materials Testing Laboratory (CMTL) to obtain compressive strengths, porosity and density of the bulk concrete comprising the walls. The mineralogy and petrography of four (4) clean core sections and one over core sample were analyzed by the U.S. Army Corps of Engineers Engineering Research Development Center (ERDC). Six (6) radiologically contaminated core sections were characterized by SRNL to identify the effects of the canyon exhaust on the mineralogy and microstructure of the affected concrete.

Compressive strength, porosity, and density of the "clean" concrete sections from the north and south walls of the 221-H Personnel Tunnel were determined from measurements made by CMTL. Mechanical and physical property results of the clean cores sections are summarized below:

- ERDC concluded that a similar mix was used for the north and south wall concretes.

- The mean compressive strength of the south wall concrete is 26.4 MPa (3835 psi) based on 20 measurements corrected for coring damage and dimension. Design strength for this concrete was 17.2 MPa (2500 psi).

- The mean compressive strength of the north wall concrete is 16.1 MPa (2336 psi) based on 29 measurements corrected for coring damage and dimension. Design strength for this concrete was 17.2 MPa (2500 psi).

  SRNL attributed the difference in the mean compressive strengths between the north and south wall concretes to be due to different aging conditions over the 60 + years of service (moist subsurface versus exposed to air or canyon exhaust). The large variance in strength measurements of the south wall cores was also attributed to the exterior wall being exposed to a moist subsurface environment, whereas the interior wall surface was exposed to air. The north wall surfaces were exposed to air on both sides and showed a lower variance.

- The mean as-received densities of the north wall and south wall concretes were typical of material containing schist and quartz aggregates; 2269.8 kg/m^3 (141.7 lbs/ft^3) and 2275 kg/m^3 (142.0 lbs/ft^3) for the north and south walls, respectively.

- The mean porosities transmitting moisture and air were relatively high, 18.6 and 17.4 volume % for the north and south wall, respectively.

Concrete in the south wall and portion of the north wall of the Personnel Tunnel which was unaffected / unaltered by exposure to the canyon exhaust showed no indication of deleterious chemical alteration or reactions such as ASR. ERDC concurred with this observation and concluded that the concrete in these walls is not expected to lose strength in the future due to normal aging.

ERDC observed rims/coatings on surfaces of some schist (silica-rich) aggregates. They identified the material comprising the rims as clay, either kaolinite or illite. Clay was also observed in the matrix mixed with the cement hydration phases. These features were interpreted as being contaminants brought into the mix on the aggregates. ERDC observed small microcracks, some of which appeared to be infilled with secondary mineralization and high capillary porosity which was attributed to early age shrinkage resulting from high water to cement ratios in the fresh concrete. No indication of cracking due to mechanical load or post curing expansion was observed. These conclusion are based on the ERDC petrographic analysis.[14]

The SRNL suite of tests and measurements made on the radioactive core sections focused on identifying and understanding depth-dependent changes that occurred in the concrete and paste/matrix as a function of distance from the surface exposed to the canyon exhaust environment. It was not possible to quantify the mechanical properties of the north wall concrete affected / altered by exposure to the canyon exhaust with the tests that were performed. There is no standard protocol for directly measuring mechanical strength gradients in the affected region of the concrete exposed to the canyon exhaust. Matrix microhardness and ultrasonic pulse velocity as a function of distance from the exposed surface were used to provide an indication of potential changes in relative density and hardness both of which may be indicators of relative strength. A summary of the test results is provided below:

- Visual examination indicated:
    - Cores were recovered and received at SRNL intact. Except for core N6-D which was damaged during coring operations. Angular schist aggregates up to 38 mm (1½ inch) in size protruded from all five intact core sections exposed to the exhaust. The aggregates and the quartz sand grains were securely anchored in the matrix. Dislodging the aggregates and surrounding matrix required a hammer and chisel. The matrix was not friable or powdery or obviously fractured.
    - The exposed surface (coarse aggregate, sand, and matrix) of these cores had a glossy (varnished) appearance which was inferred to be the result of chemical and/or physical polishing.
    - The cores sections were a darker color from the exposed surface to a depth of about 38 to 64 mm (1½ to 2 ½) inches. The darker portion of the core were referred to as the “affected zone” even though the cause of the color was initially unknown. The darker color portion of Core N1-D extended about 89 mm (3 ½ inches) from the surface but was not considered representative of the rest of the wall because it was located directly in front of the warm canyon exhaust entry point.
- Depth discrete analyses of the mineralogy, microstructure, and leachability of soluble ions in the matrix indicated:
    - Two concurrent chemical alteration mechanisms altered the matrix phases (1) nitric acid attack and (2) carbonation in the affected zone.
    - The schist and quartz aggregates were not affected by either of these chemical alteration mechanisms. They were physically affected by the wind erosion from the canyon exhaust.
    - Nitric acid dissolution of matrix minerals, primarily portlandite, $Ca(OH)_2$, and carbonation of soluble calcium, resulted in formation of secondary calcite, $CaCO_3$ in the matrix and were the only forms of chemical alteration observed.
    - Secondary calcite was intermixed with hydrated portland cement phases and was an integral part of the cementing material in the altered matrix.

  - The presence of soluble calcium nitrate in the concrete pore solution was inferred from leaching data. Soluble nitrate and calcium ions were extracted from pulverized matrix samples.

  - Neither alkali silica reaction, nor cracking that could be attributed to any other expansive reactions were observed in the radioactive core sections analyzed by SRNL. This observation was confirmed by the ERDC characterization of the non-radioactive core sections from the north and south wall of the 221-H Personnel Tunnel.

- The alkalinity of the radiological core sections indicated some variability but overall the pH was > 10.2 which is sufficient to maintain rebar passivation.

- X-ray computed tomography (XCT) imaging indicated that neither delamination along planes parallel to the exposed surface nor macrocracking nor density gradients in the matrix or in the concrete itself were present in the two full-length exposed core sections evaluated.

- Microhardness data showed that the average microhardness values of the depth-discrete matrix measurements were not statistically different as a function of distance from the exposed surface.

- UPV data were confounded because many material properties in these cores, e.g., density, porosity, moisture, mineralogy were depth dependent and consequently may have influenced the measured velocities in ways and to degrees that were not quantified in this evaluation. A correlation of UPV and compressive strength for the bulk north and south wall concrete was attempted but could not be applied to the portions of the cores affected by exposure to the canyon exhaust for the same reason.

In summary, loss of the concrete wall thickness, i.e. erosion, in the H-Canyon Cross-over Tunnel and Exhaust Tunnel has been documented in surveillance activities over many years.[8] Exposed aggregates and rebar and concrete debris on the floor have been observed in these tunnels and have been attributed to a combination of physical and chemical attack by the canyon exhaust. Results from this study suggest a chemically-assisted erosion mechanism is responsible for the observed loss of wall thickness. This study focused on the chemical reactions involved and concluded that concurrent acid attack and carbonation are responsible for the chemical and mineralogical gradients observed in the affected concrete. The exhaust air flow erosion conditions have not been investigated in detail.

The composite results from the characterization study performed on the radiologically contaminated north wall core sections do not conclusively demonstrate a change in compressive strength relative to the mean compressive strength of the unaffected north wall measured in 2017. That is, several depth-dependent material changes were observed, however there is no firm case to conclude that these material changes were manifested in an increase or a decrease from the bulk concrete compressive strength.

8.0 References

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Appendix A. Radiologically Contaminated North Wall Concrete Cores - Field Alkalinity Test Photographs

SRNL performed the alkalinity dye test (phenolphthalein color indicator tests) at a field location in H-Area shortly after each core was removed from the wall. The images in this section show the results of the alkalinity dye test for the radiologically contaminated north wall cores. If the area to which the dye was applied remains pink to red, the pH of the concrete is greater than 10. The brighter and redder the color, the higher is the pH. If the dyed area is not stained pink, the concrete pH is less than 8.2.

Figure A-1. Field Alkalinity Test on Core N-3-D.

Figure A-2. Field Alkalinity Test on Core N-4-D

Appendix B. Radiologically Contaminated North Wall Concrete Cores - UPV Inspection Sheets.

ULTRASONIC PULSE VELOCITY INSPECTION REPORT

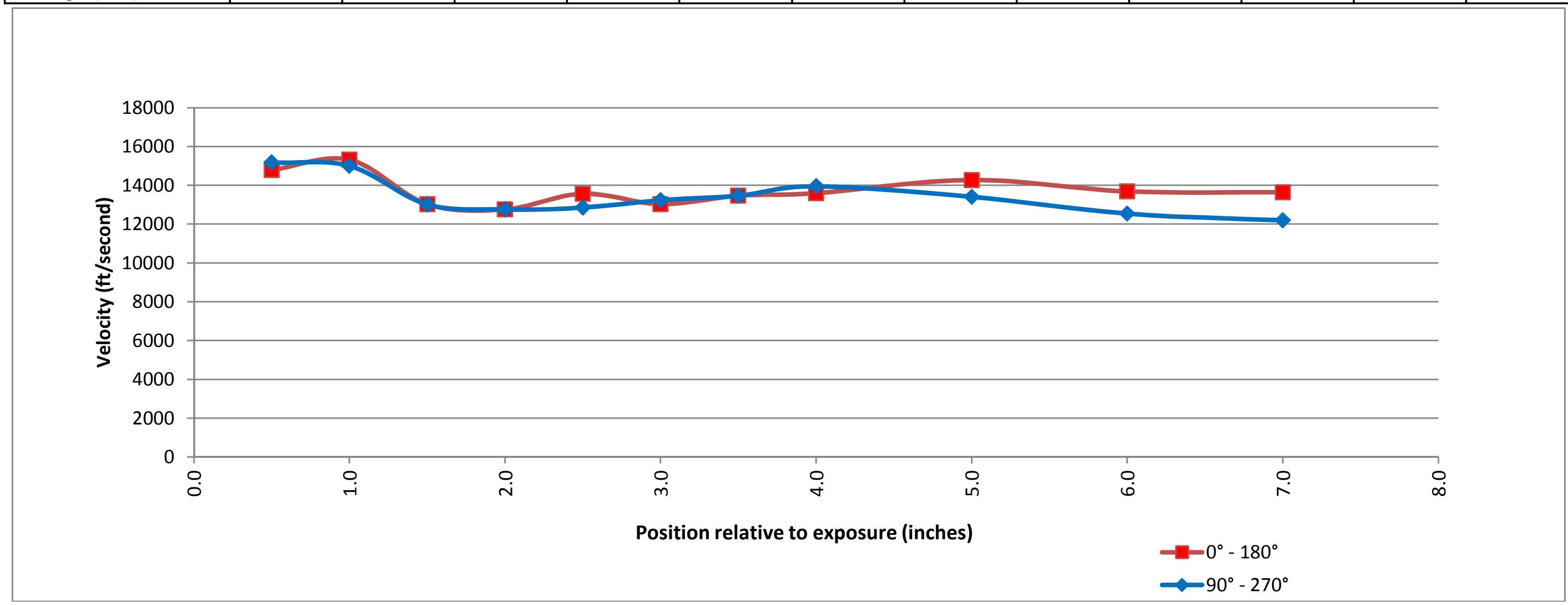
Area / System:	**H-Canyon / North Wall Concrete Cores**	**Examiner:**	**Jason N Corley**	**NDE Job #:**	H20170369
Number of Samples:	**1 Core Sample**	**Date:**	April 26th, 2017	**NDE Report #:**	2017-IR-11-0382

Direct Transmission Cross Sectional Scans

221-H-PT3-N-1D	**0° - 180°**	**1/2"**	**1"**	**1-1/2"**	**2"**	**2-1/2"**	**3"**	**3-1/2"**	**4"**	**5"**	**6"**	**7"**	**8"**	**Average**
Transmission Time		**21.1**	**20.5**	**24.1**	**24.3**	**23**	**24.2**	**23.4**	**23.1**	**22**	**22.8**	**22.8**	N/A	22.8
Distance (ft)		0.312	0.314	0.314	0.310	0.312	0.314	0.315	0.314	0.314	0.312	0.311	N/A	0.313
Pulse Velocity (ft/s)		**14787**	**15317**	**13029**	**12757**	**13565**	**13029**	**13462**	**13593**	**14273**	**13684**	**13640**	N/A	**13740**
Physical Measurement (in)		3.745	3.765	3.765	3.725	3.745	3.765	3.755	3.762	3.770	3.745	3.735	N/A	3.753
		TUNNEL SIDE DISCOLORATION									FRACTURED END			

Direct Transmission Cross Sectional Scans

221-H-PT3-N-1D	**90° - 270°**	**1/2"**	**1"**	**1-1/2"**	**2"**	**2-1/2"**	**3"**	**3-1/2"**	**4"**	**5"**	**6"**	**7"**	**8"**	**Average**
Transmission Time		**20.5**	**20.8**	**23.9**	**24.3**	**24.2**	**23.5**	**23.1**	**22.3**	**23.2**	**24.8**	**25.6**	N/A	23.3
Distance (ft)		0.311	0.312	0.311	0.310	0.311	0.311	0.311	0.311	0.311	0.310	0.312	N/A	0.311
Pulse Velocity (ft/s)		**15171**	**15000**	**13013**	**12757**	**12851**	**13234**	**13463**	**13946**	**13405**	**12540**	**12188**	N/A	**13415**
Physical Measurement (in)		3.730	3.740	3.730	3.725	3.730	3.730	3.728	3.732	3.732	3.720	3.740	N/A	3.730
		TUNNEL SIDE DISCOLORATION									FRACTURED END			**Overall Average**
Position (in)		**0.5**	**1.0**	**1.5**	**2.0**	**2.5**	**3.0**	**3.5**	**4.0**	**5.0**	**6.0**	**7.0**	**8.0**	
Average (ft/s)		**14979**	**15159**	**13021**	**12757**	**13208**	**13132**	**13463**	**13770**	**13839**	**13112**	**12914**		**13577**



ULTRASONIC PULSE VELOCITY INSPECTION REPORT

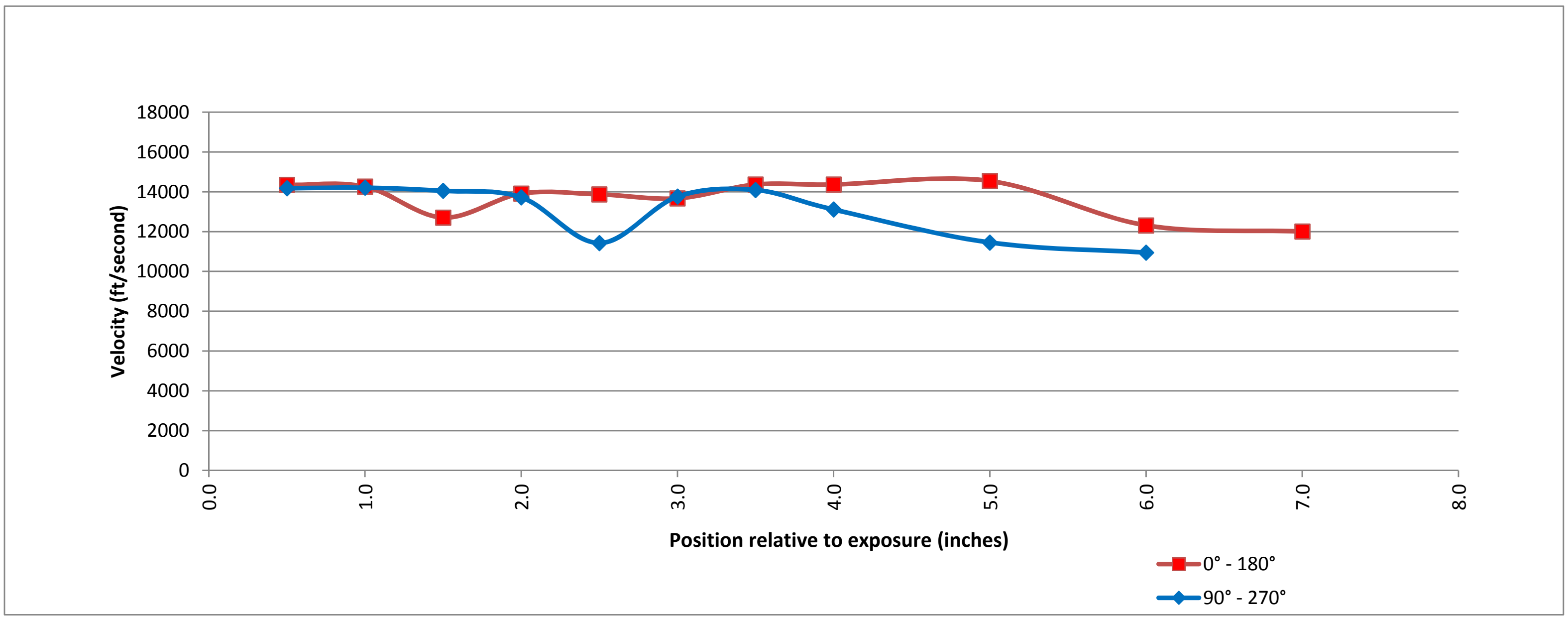
Area / System:	**H-Canyon / North Wall Concrete Cores**	**Examiner:**	**Jason N Corley**	**NDE Job #:**	H20170369
Number of Samples:	**1 Core Sample**	**Date:**	April 20th, 2017	**NDE Report #:**	2017-IR-11-0382

Direct Transmission Cross Sectional Scans

221-H-PT3-N-2C	**0° - 180°**	**1/2"**	**1"**	**1-1/2"**	**2"**	**2-1/2"**	**3"**	**3-1/2"**	**4"**	**5"**	**6"**	**7"**	**8"**	**Average**
Transmission Time		**32.8**	**33**	**37.2**	**33.9**	**34**	**34.5**	**32.9**	**32.9**	**32.5**	**38.3**	**39.2**	N/A	34.7
Distance (ft)		0.471	0.471	0.473	0.472	0.471	0.472	0.473	0.473	0.473	0.472	0.471	N/A	0.472
Pulse Velocity (ft/s)		**14351**	**14264**	**12708**	**13915**	**13874**	**13673**	**14368**	**14368**	**14545**	**12317**	**12009**	N/A	**13672**
Physical Measurement (in)		5.650	5.655	5.673	5.660	5.655	5.660	5.668	5.670	5.679	5.668	5.665	N/A	5.670
		TUNNEL SIDE DISCOLORATION									FRACTURED END			

Direct Transmission Cross Sectional Scans

221-H-PT3-N-2C	**90° - 270°**	**1/2"**	**1"**	**1-1/2"**	**2"**	**2-1/2"**	**3"**	**3-1/2"**	**4"**	**5"**	**6"**	**7"**	**8"**	**Average**
Transmission Time		**33.1**	**33.2**	**33.5**	**34.3**	**41.2**	**34.2**	**33.4**	**35.9**	**41.1**	**43**	**N/A**	N/A	36.3
Distance (ft)		0.471	0.472	0.471	0.471	0.471	0.471	0.471	0.471	0.471	0.471	N/A	N/A	0.471
Pulse Velocity (ft/s)		**14178**	**14208**	**14051**	**13724**	**11427**	**13764**	**14093**	**13112**	**11454**	**10948**	N/A	N/A	**13096**
Physical Measurement (in)		5.652	5.658	5.655	5.654	5.655	5.652	5.650	5.654	5.658	5.657	N/A	N/A	5.655
		TUNNEL SIDE DISCOLORATION									FRACTURED END			**Overall Average**
Position (in)		**0.5**	**1.0**	**1.5**	**2.0**	**2.5**	**3.0**	**3.5**	**4.0**	**5.0**	**6.0**	**7.0**	**8.0**	
Average (ft/s)		**14265**	**14236**	**13380**	**13820**	**12651**	**13719**	**14231**	**13740**	**13000**	**11633**	**12009**		**13398**



ULTRASONIC PULSE VELOCITY INSPECTION REPORT

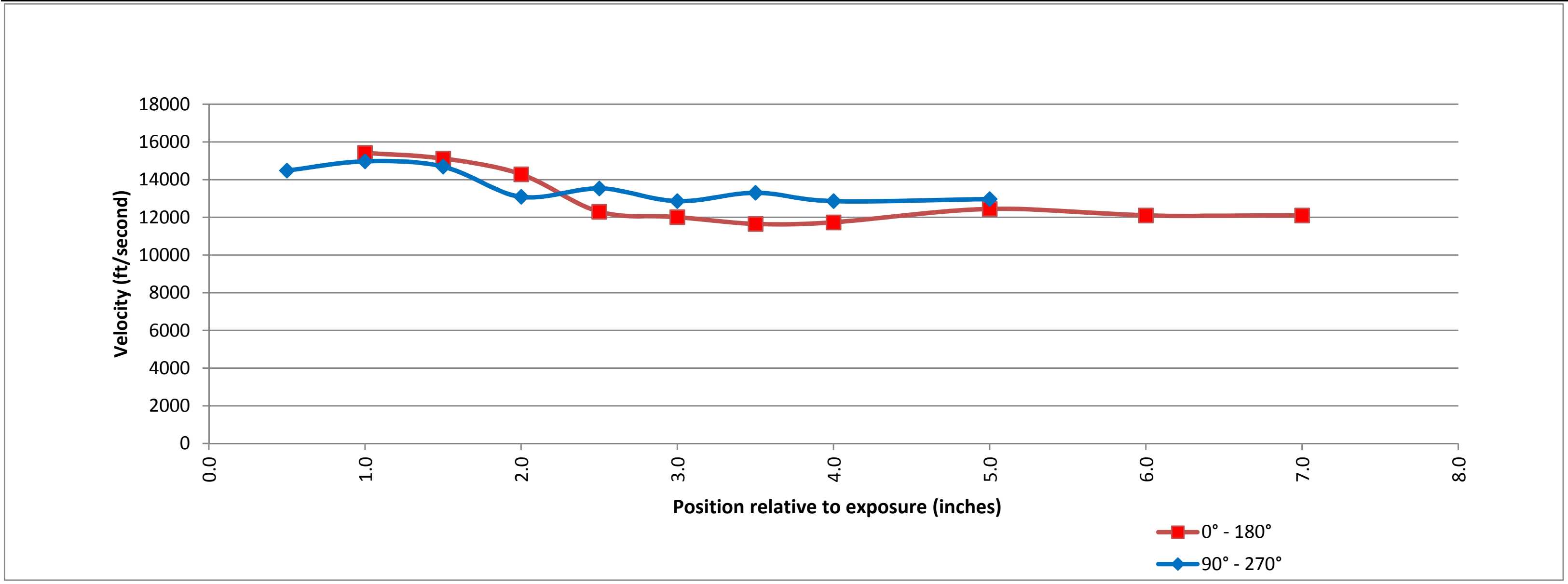
Area / System:	H-Canyon / North Wall Concrete Cores	Examiner:	Jason N Corley	NDE Job #:	H20170369
Number of Samples:	1 Core Sample	Date:	May 30th, 2017	NDE Report #:	2017-IR-11-0382

Direct Transmission Cross Sectional Scans

221-H-PT3-N-3D	0° - 180°	1/2"	1"	1-1/2"	2"	2-1/2"	3"	3-1/2"	4"	5"	6"	7"	8"	Average
Transmission Time		N/A	20.1	20.5	21.7	25.2	25.8	26.6	26.4	24.9	25.6	25.6	N/A	24.2
Distance (ft)		N/A	0.310	0.310	0.310	0.310	0.310	0.310	0.310	0.310	0.311	0.311	N/A	0.310
Pulse Velocity (ft/s)		N/A	15423	15122	14286	12302	12016	11654	11742	12450	12109	12109	N/A	12921
Physical Measurement (in)		N/A	3.723	3.721	3.721	3.721	3.721	3.721	3.721	3.721	3.730	3.726	N/A	3.723
		TUNNEL SIDE DISCOLORATION									FRACTURED END			

Direct Transmission Cross Sectional Scans

221-H-PT3-N-3D	90° - 270°	1/2"	1"	1-1/2"	2"	2-1/2"	3"	3-1/2"	4"	5"	6"	7"	8"	Average
Transmission Time		21.4	20.7	21.1	22	22.9	24.1	23.3	24.1	23.9	N/A	N/A	N/A	22.6
Distance (ft)		0.311	0.311	0.310	0.310	0.310	0.310	0.310	0.310	0.310	N/A	N/A	N/A	0.310
Pulse Velocity (ft/s)		14486	14976	14692	13091	13537	12863	13305	12863	12971	N/A	N/A	N/A	13643
Physical Measurement (in)		3.728	3.728	3.721	3.721	3.721	3.721	3.724	3.725	3.734	3.742	N/A	N/A	3.727
		TUNNEL SIDE DISCOLORATION									FRACTURED END			Overall Average
Position (in)		0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	5.0	6.0	7.0	8.0	
Average (ft/s)		14486	15200	14907	13689	12920	12440	12480	12303	12711	12109	12109		13263



ULTRASONIC PULSE VELOCITY INSPECTION REPORT

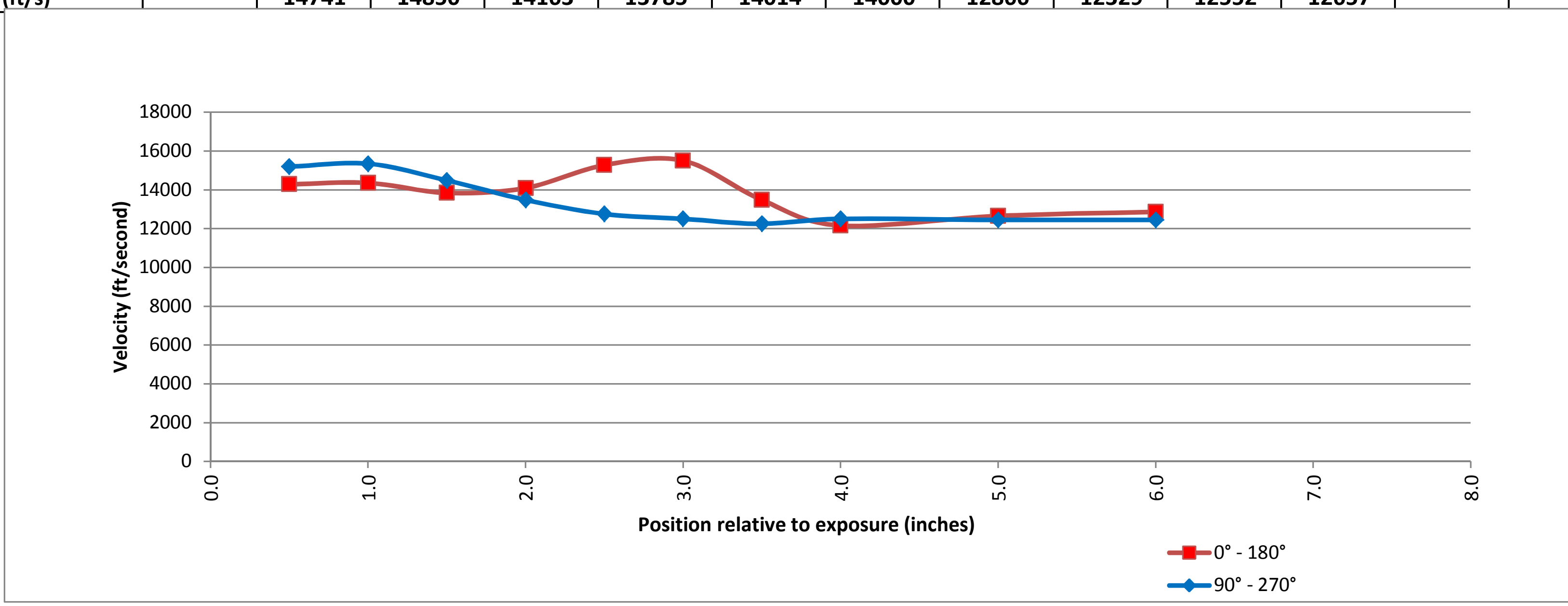
Area / System:	**H-Canyon / North Wall Concrete Cores**	**Examiner:**	**Jason N Corley**	**NDE Job #:**	H20170369
Number of Samples:	**1 Core Sample**	**Date:**	May 30th, 2017	**NDE Report #:**	2017-IR-11-0382

Direct Transmission Cross Sectional Scans

221-H-PT3-N-4D	**0° - 180°**	**1/2"**	**1"**	**1-1/2"**	**2"**	**2-1/2"**	**3"**	**3-1/2"**	**4"**	**5"**	**6"**	**7"**	**8"**	**Average**
Transmission Time		**21.7**	**21.6**	**22.4**	**22**	**20.3**	**20**	**23**	**25.5**	**24.5**	**24.1**	N/A	N/A	22.5
Distance (ft)		0.310	0.310	0.310	0.310	0.310	0.310	0.310	0.310	0.310	0.311	N/A	N/A	0.310
Pulse Velocity (ft/s)		14286	14352	13839	14091	15271	15500	13478	12157	12653	12863	N/A	N/A	13849
Physical Measurement (in)		3.720	3.720	3.721	3.721	3.725	3.725	3.725	3.725	3.725	3.730	N/A	N/A	3.726
		TUNNEL SIDE DISCOLORATION										FRACTURED END		

Direct Transmission Cross Sectional Scans

221-H-PT3-N-4D	**90° - 270°**	**1/2"**	**1"**	**1-1/2"**	**2"**	**2-1/2"**	**3"**	**3-1/2"**	**4"**	**5"**	**6"**	**7"**	**8"**	**Average**
Transmission Time		**21.7**	**21.6**	**22.4**	**22**	**20.3**	**20**	**23**	**25.5**	**24.5**	**24.1**	N/A	N/A	22.5
Distance (ft)		0.313	0.313	0.310	0.310	0.310	0.310	0.310	0.310	0.310	0.310	N/A	N/A	0.311
Pulse Velocity (ft/s)		15196	15347	14486	13478	12757	12500	12253	12500	12450	12450	N/A	N/A	13342
Physical Measurement (in)		3.755	3.755	3.721	3.721	3.721	3.721	3.721	3.721	3.721	3.721	N/A	N/A	3.721
		TUNNEL SIDE DISCOLORATION										FRACTURED END		**Overall Average**
Position (in)		**0.5**	**1.0**	**1.5**	**2.0**	**2.5**	**3.0**	**3.5**	**4.0**	**5.0**	**6.0**	**7.0**	**8.0**	
Average (ft/s)		**14741**	**14850**	**14163**	**13785**	**14014**	**14000**	**12866**	**12329**	**12552**	**12657**			**13595**



ULTRASONIC PULSE VELOCITY INSPECTION REPORT

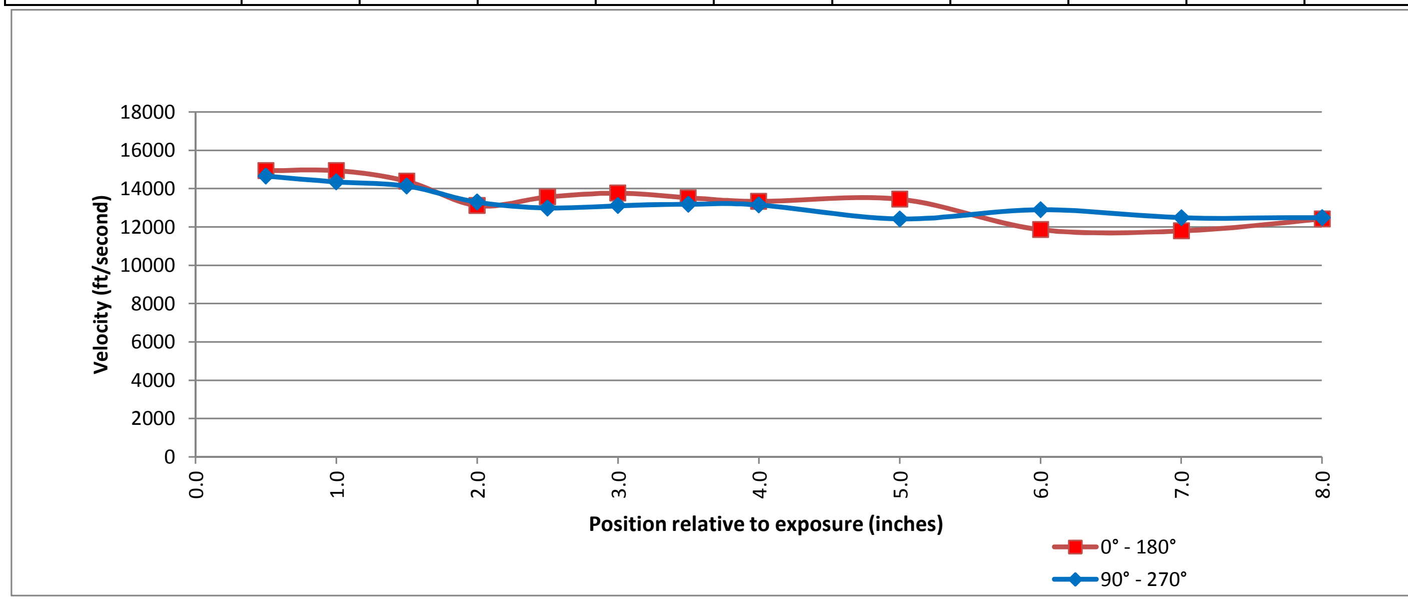
Area / System:	**H-Canyon / North Wall Concrete Cores**	**Examiner:**	**Jason N Corley**	**NDE Job #:**	H20170369
Number of Samples:	**2 Core Samples**	**Date:**	May 18th, 2017	**NDE Report #:**	2017-IR-11-0382

Direct Transmission Cross Sectional Scans

221-H-PT3-N-5C	0° - 180°	1/2"	1"	1-1/2"	2"	2-1/2"	3"	3-1/2"	4"	5"	6"	7"	8"	Average
Transmission Time		31.6	31.6	32.8	36	34.8	34.3	34.9	35.4	35.1	39.8	38.5	36.9	35.1
Distance (ft)		0.472	0.472	0.472	0.472	0.472	0.472	0.472	0.472	0.472	0.472	0.454	0.458	0.469
Pulse Velocity (ft/s)		14937	14937	14390	13111	13563	13761	13524	13333	13447	11859	11792	12412	13422
Physical Measurement (in)		5.660	5.660	5.660	5.660	5.660	5.660	5.660	5.665	5.665	5.660	5.448	5.499	5.630
		TUNNEL SIDE DISCOLORATION									FRACTURED END			

Direct Transmission Cross Sectional Scans

221-H-PT3-N-5C	90° - 270°	1/2"	1"	1-1/2"	2"	2-1/2"	3"	3-1/2"	4"	5"	6"	7"	8"	Average
Transmission Time		32.2	32.9	33.4	35.5	36.6	36	35.8	35.9	38	36.6	37.8	37.8	35.7
Distance (ft)		0.472	0.472	0.472	0.472	0.472	0.472	0.472	0.472	0.472	0.456	0.456	0.457	0.468
Pulse Velocity (ft/s)		14658	14347	14132	13296	12986	13111	13184	13148	12421	12896	12487	12487	13263
Physical Measurement (in)		5.660	5.660	5.660	5.660	5.658	5.658	5.665	5.660	5.660	5.473	5.474	5.484	5.614
		TUNNEL SIDE DISCOLORATION									FRACTURED END			Overall Average
Position (in)		0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	5.0	6.0	7.0	8.0	
Average (ft/s)		14798	14642	14261	13204	13275	13436	13354	13241	12934	12378	12140	12450	13342



Note: 221-H-PT3-N-6-D had one area that was susceptible to ultrasonic pulse transmission. This area revealed a transimission time of 23.5 and a pulse velocity 13404.

Appendix C. X-Ray Diffraction Powder Patterns for Radiologically Contaminated North Wall Concrete Cores.

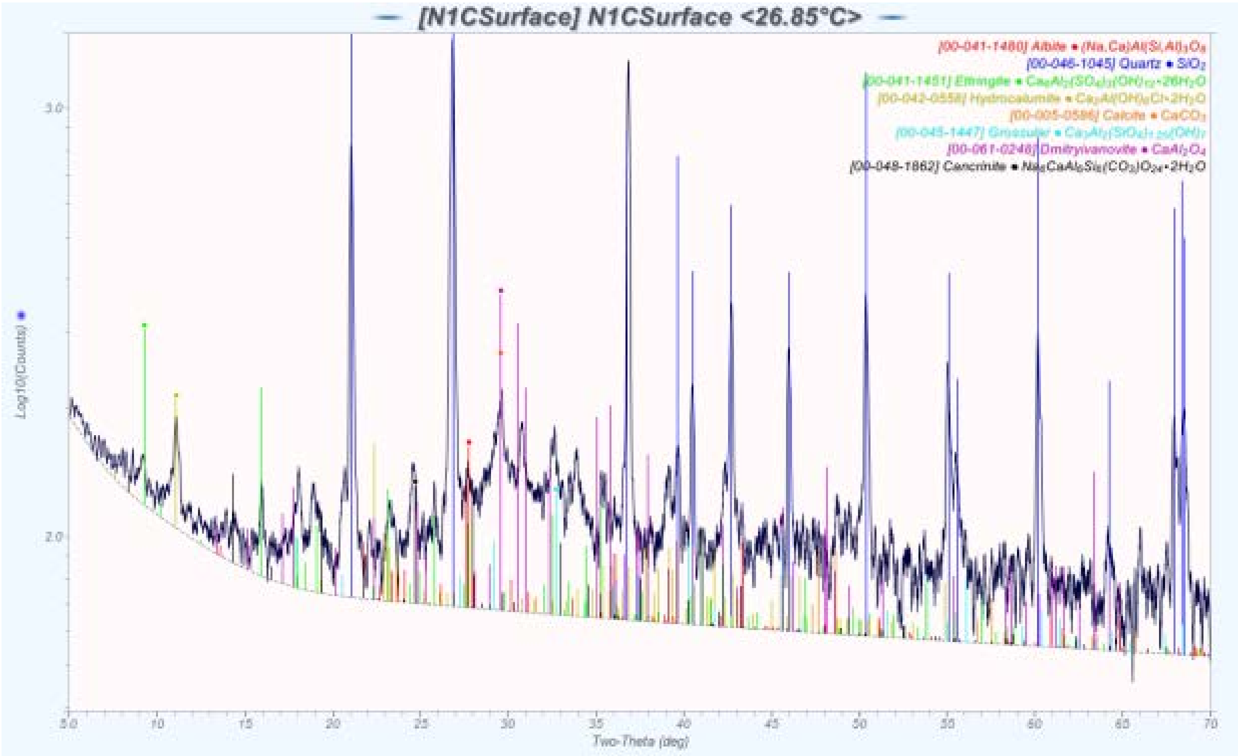


Figure C-1. XRD Pattern for Core N-1-D Surface.

0.5 to 1 inch

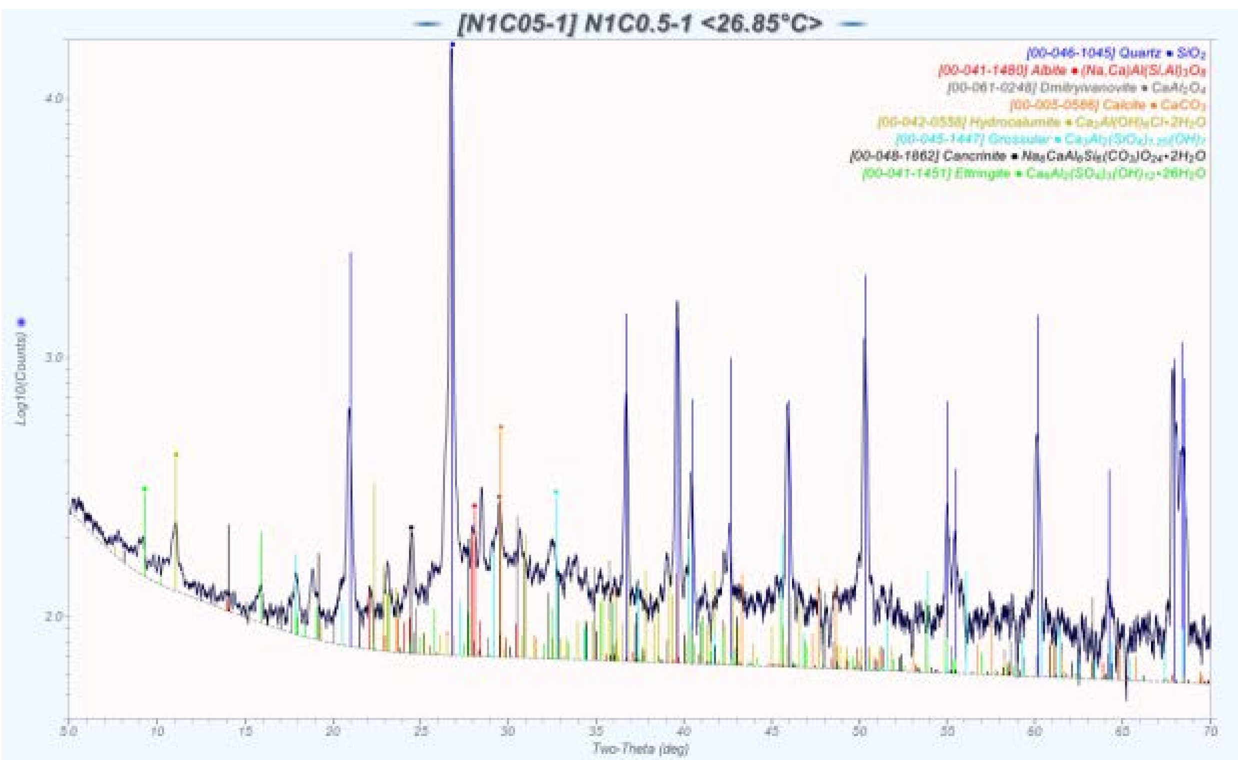


Figure C-2. XRD Pattern for Core N-1-D 1 to 1.5 inches.

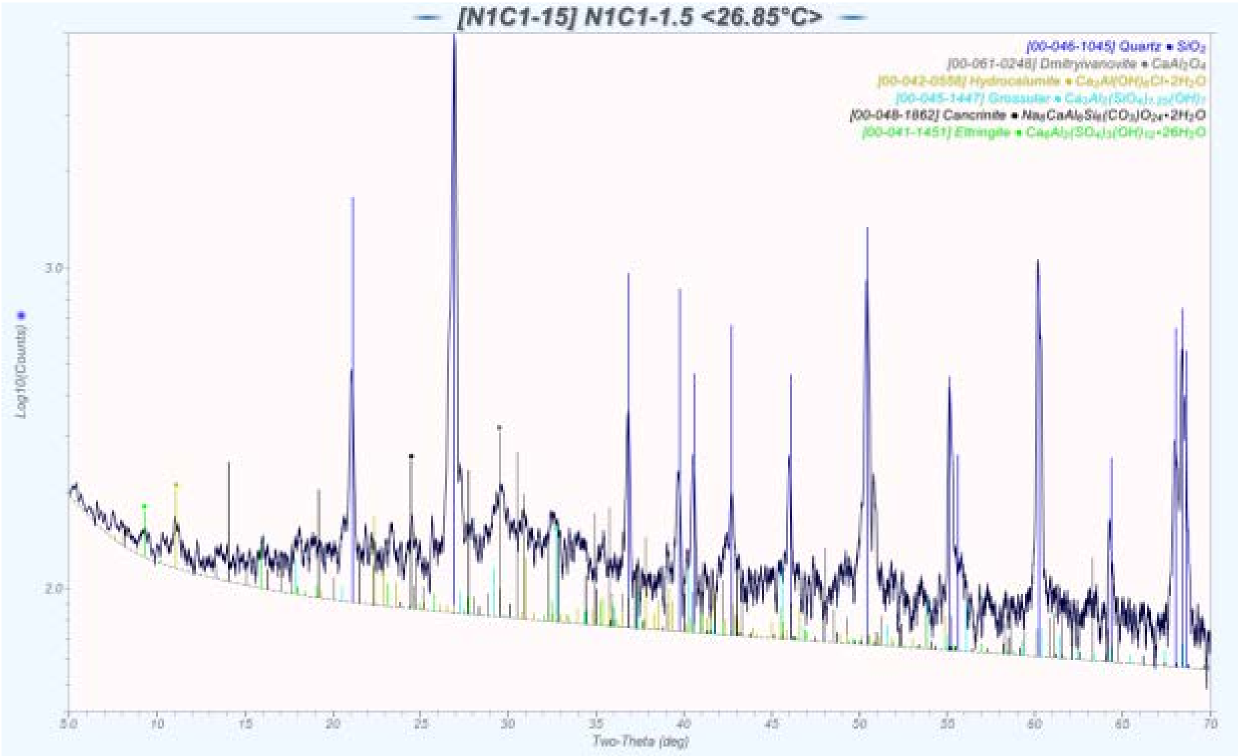


Figure C-3. XRD Pattern for Core N-1-D 1 to 1.5 inches.

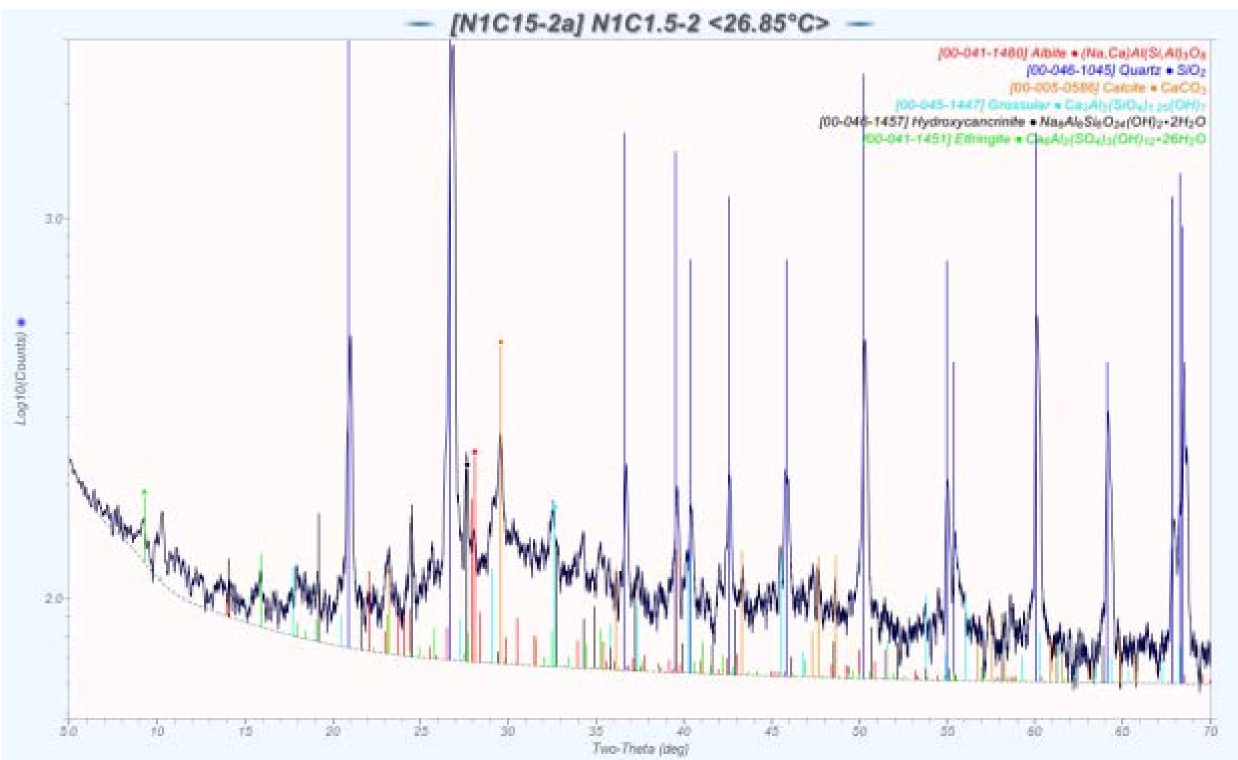


Figure C-4. XRD Pattern for Core N-1-D 1.5 to 2 inches.

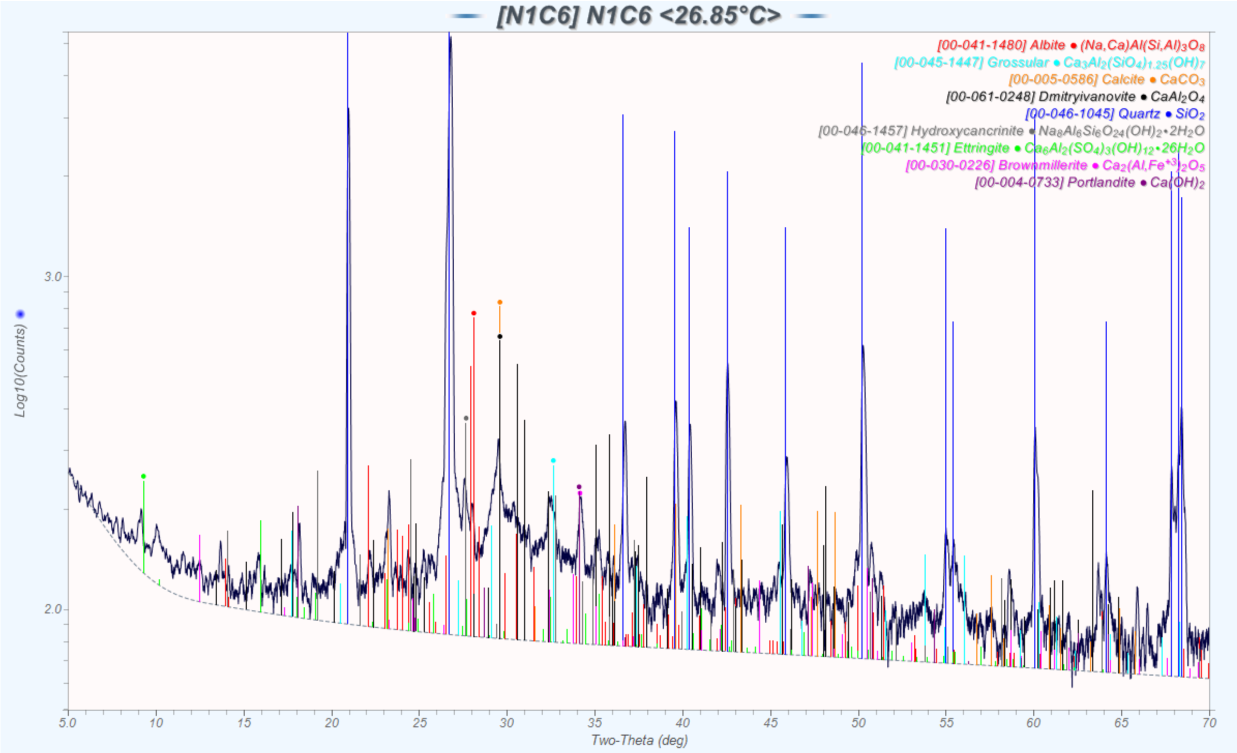


Figure C-5. XRD Pattern for Core N-1-D 6 inches.

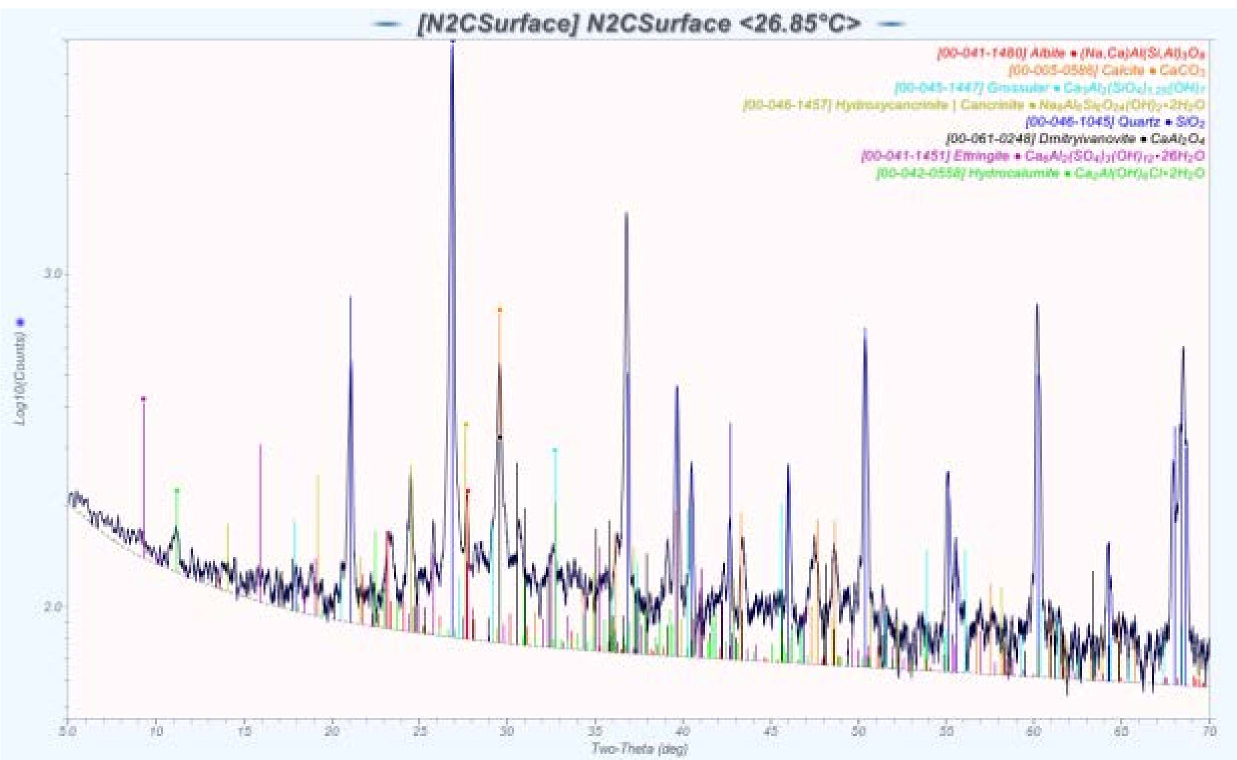


Figure C-6. XRD Pattern for Core N-2-C Surface.

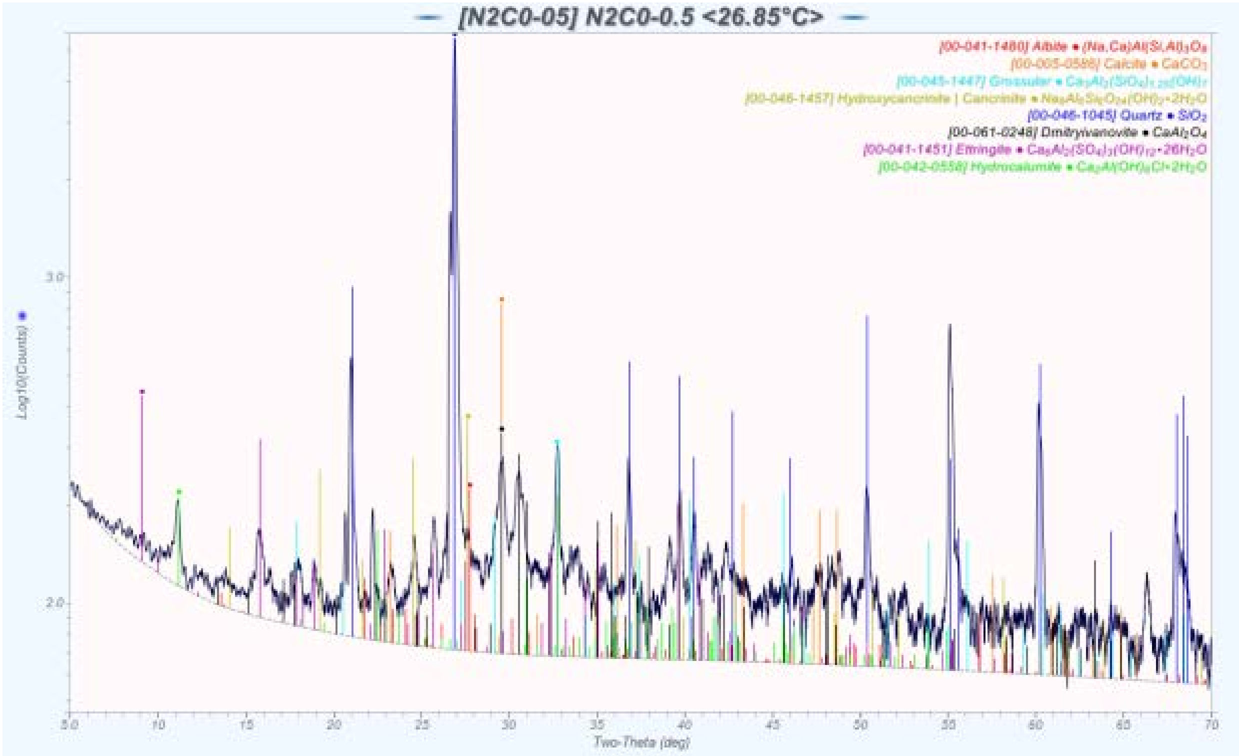


Figure C-7. XRD Pattern for Core N-2-C 0 to 0.5 inches.

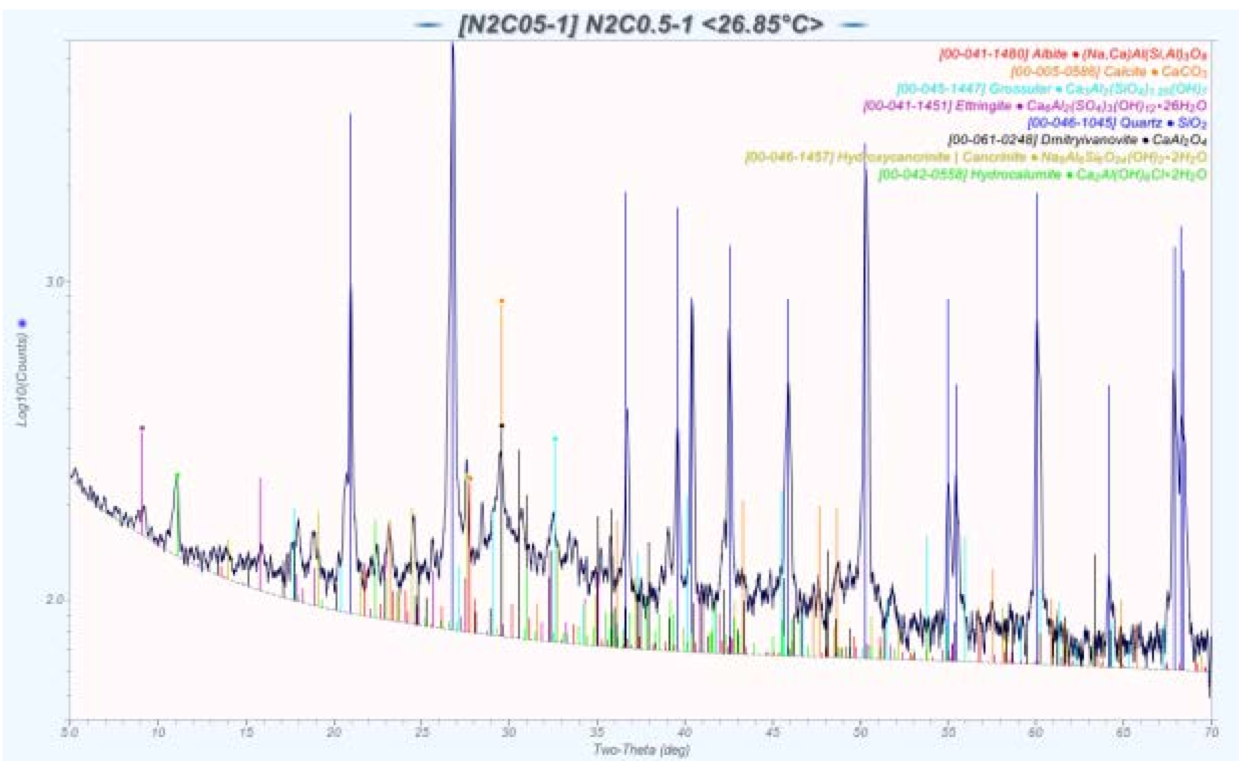


Figure C-8. XRD Pattern for Core N-2-C 0.5 to 1 inch.

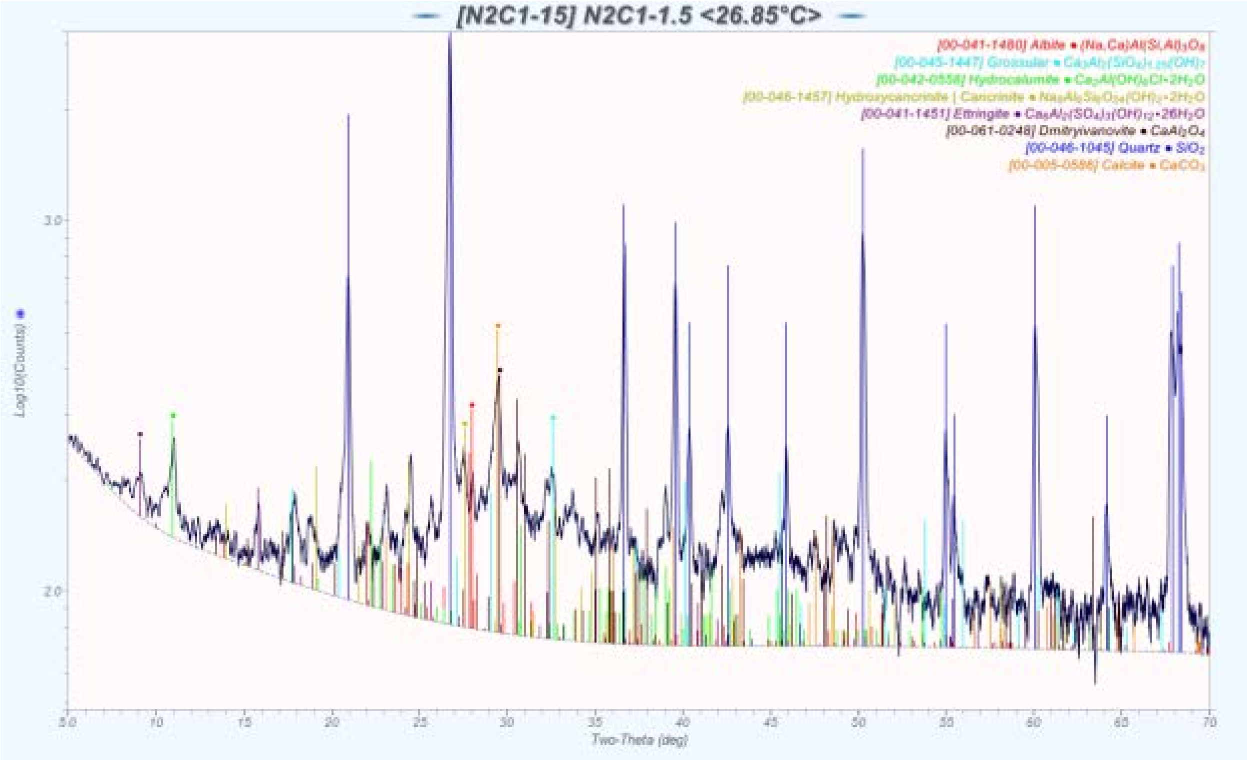


Figure C-9. XRD Pattern for Core N-2-C 1 to 1.5 inches.

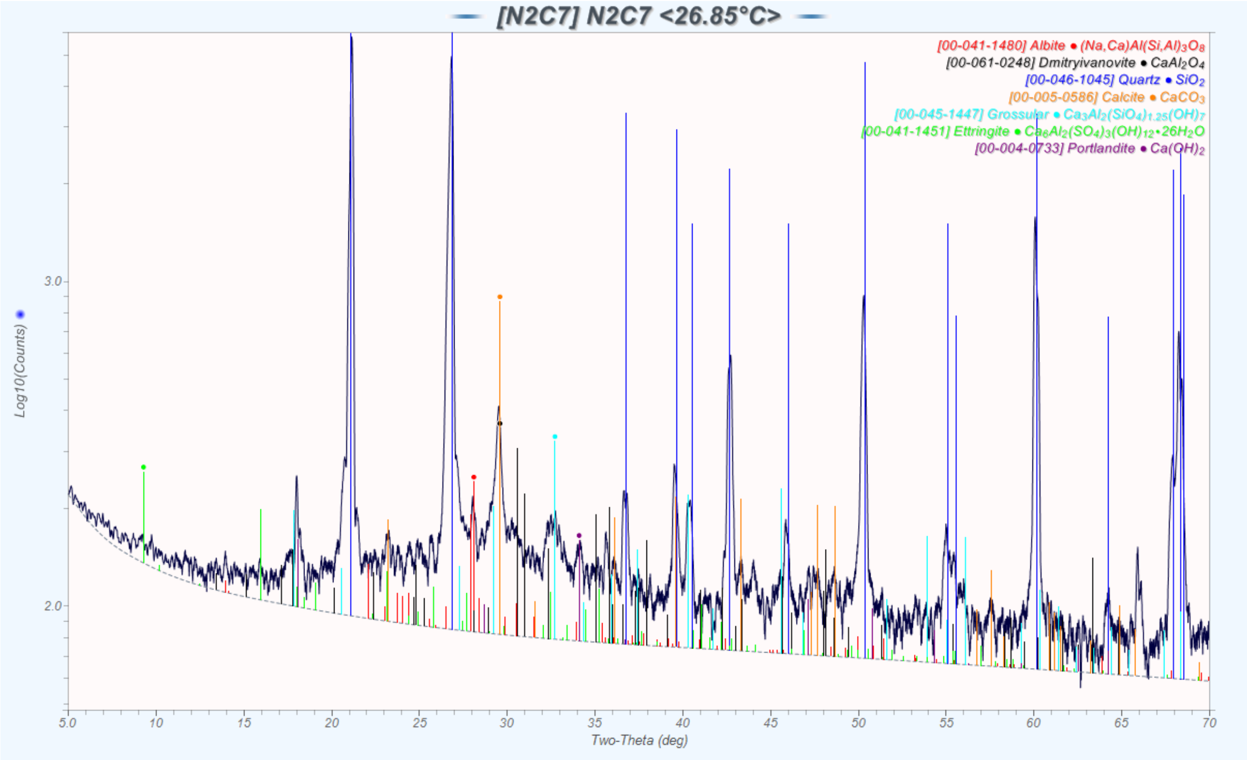


Figure C-10. XRD Pattern for Core N-2-C 7 inches.

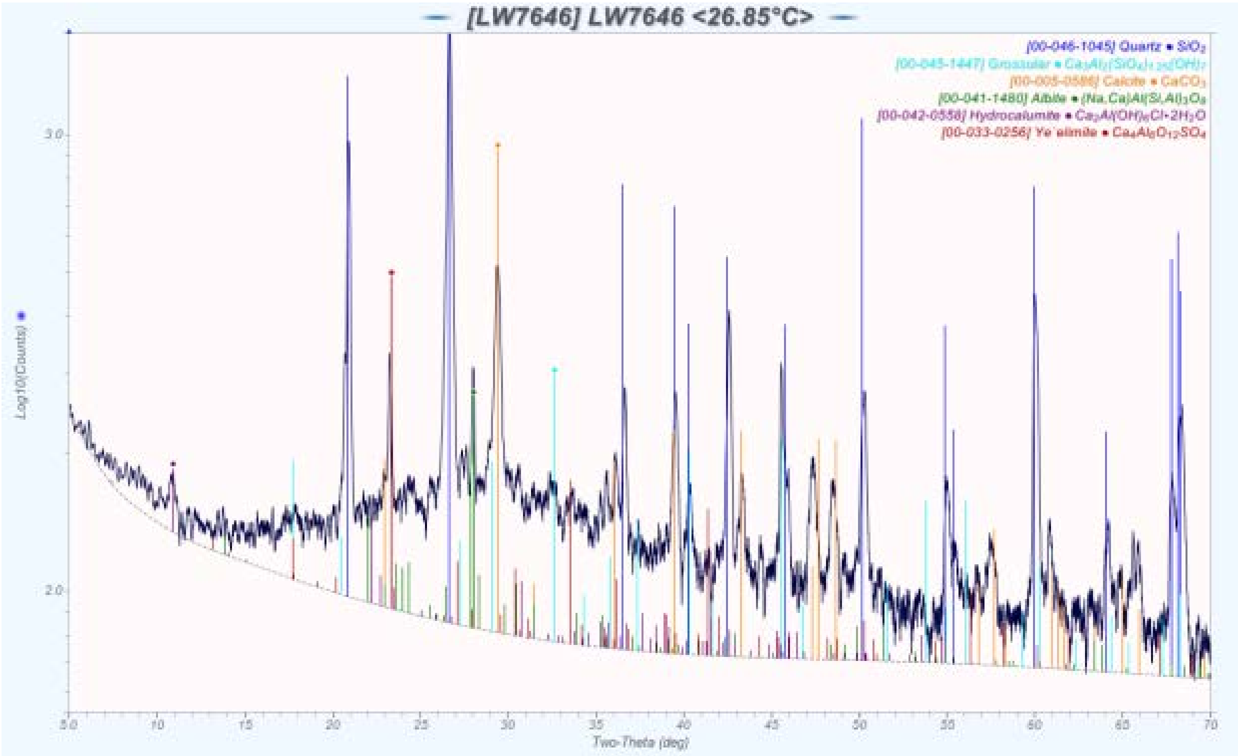


Figure C-11. XRD Pattern for Core N-3-D 0 to 0.025 inches.

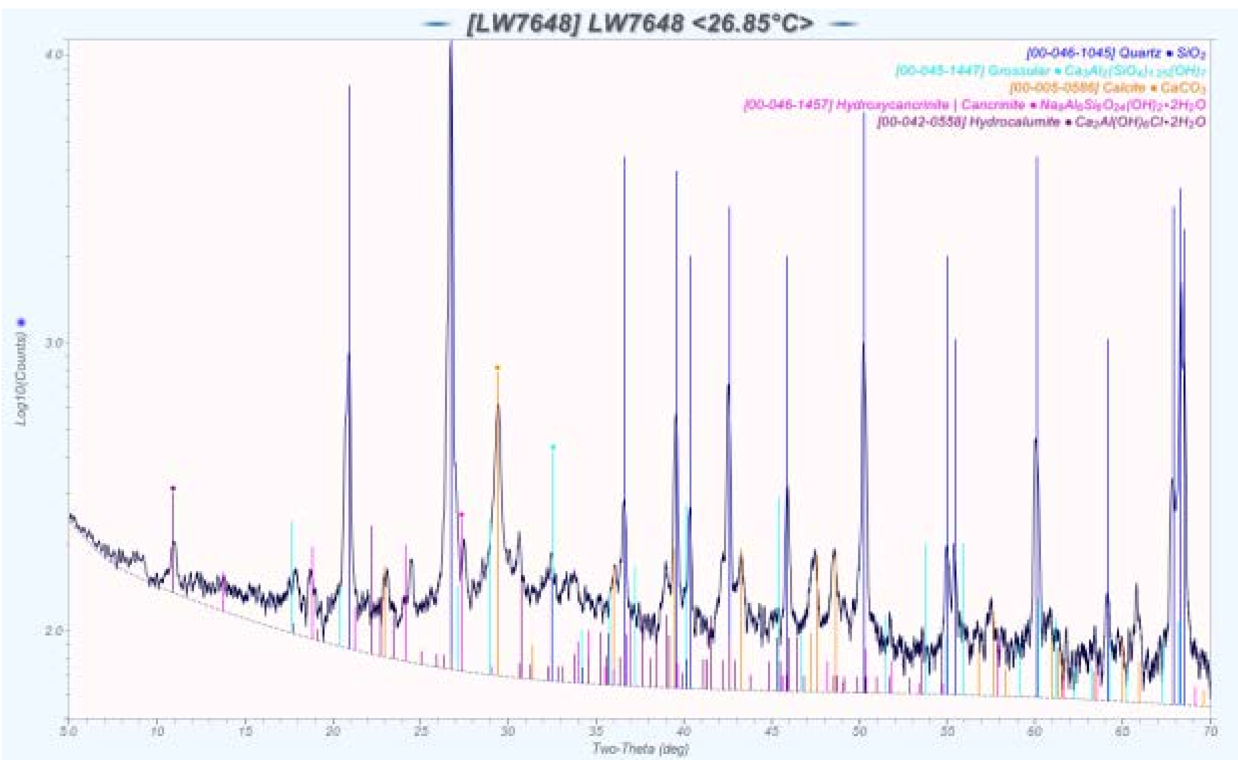


Figure C-12. XRD Pattern for Core N-3-D 0.5 to 0.75 inches.

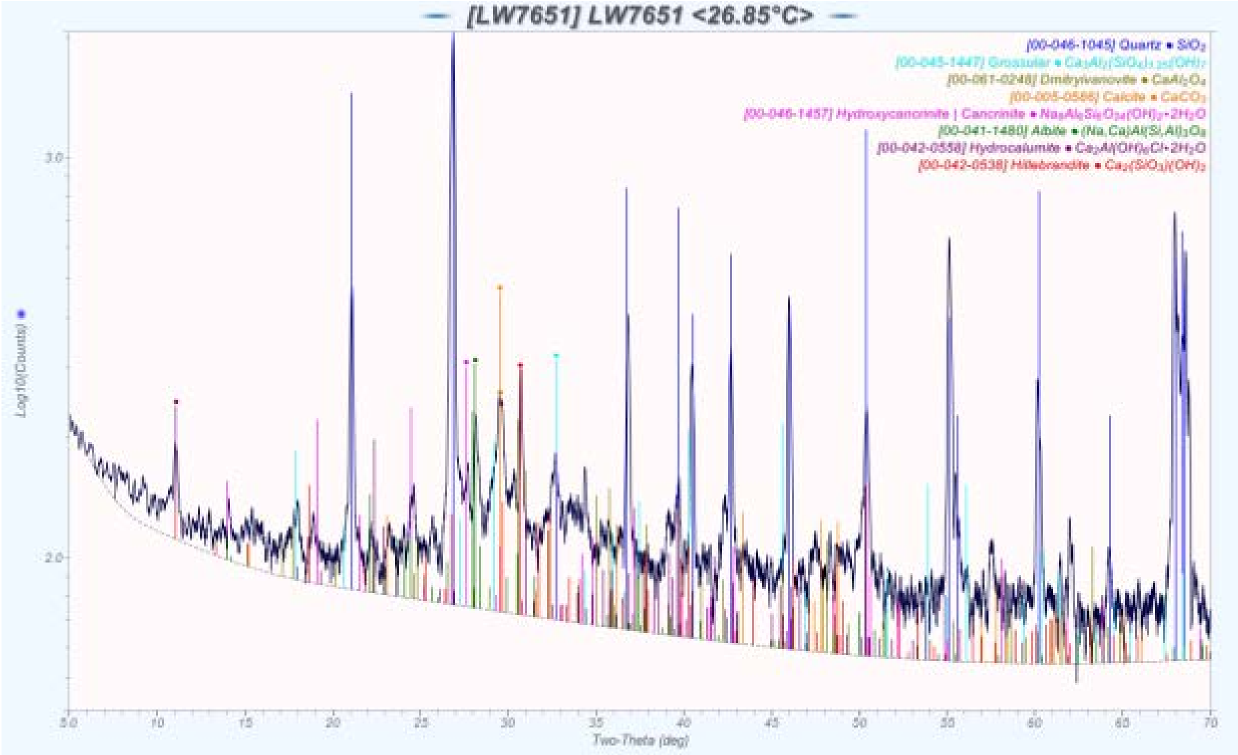


Figure C-13. XRD Pattern for Core N-3-D 1.5 to 2 in.

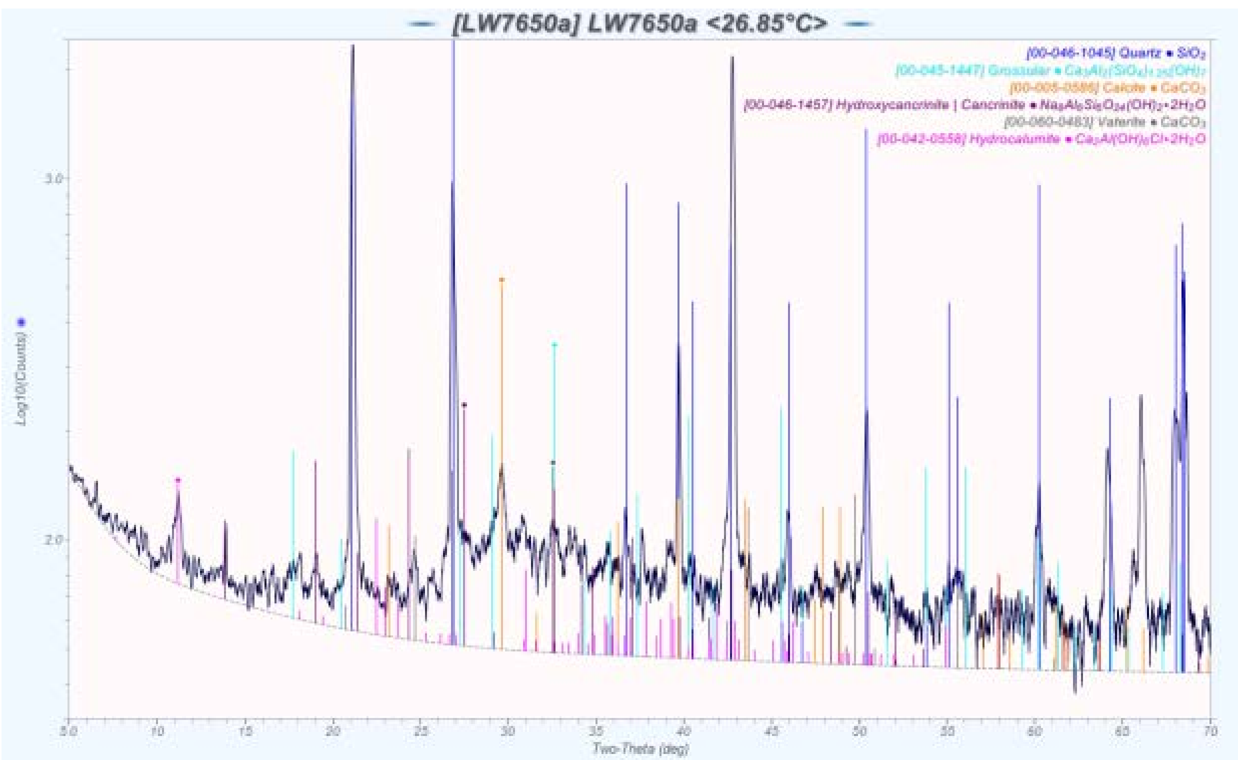


Figure C-14. XRD Pattern for Core N-3-D 1 to 1.5 in.

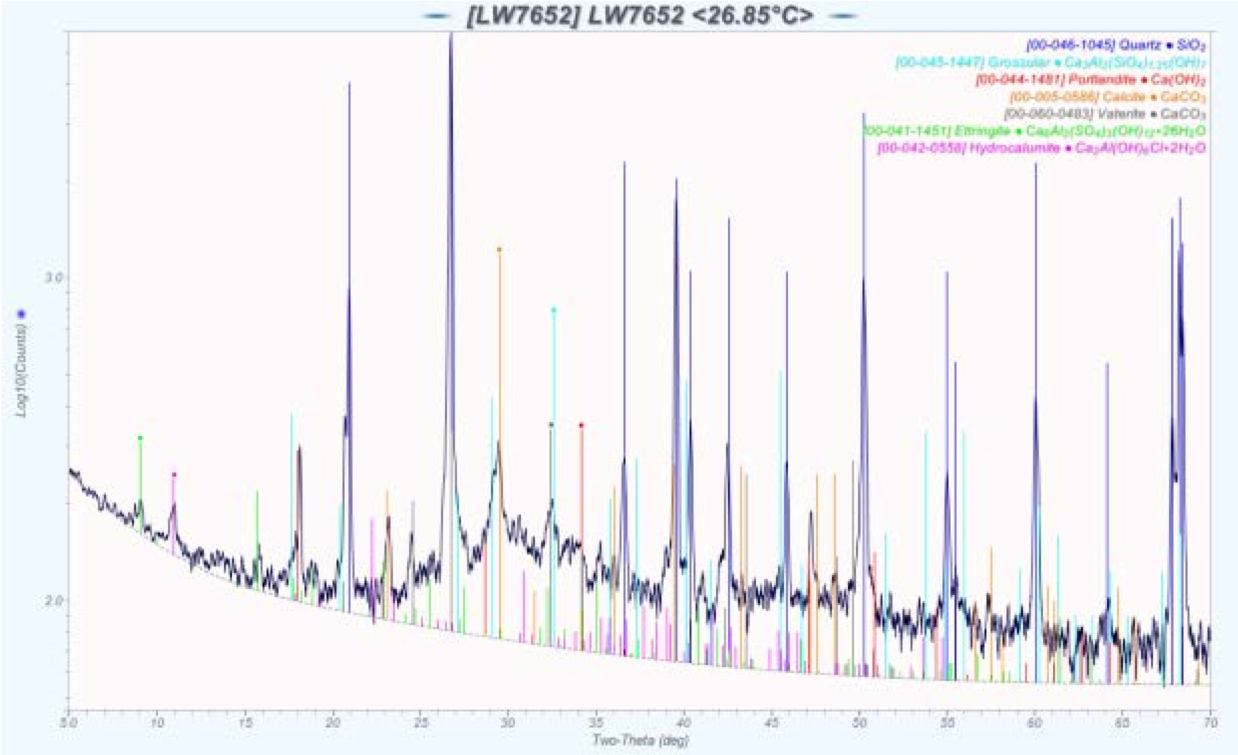


Figure C-15. XRD Pattern for Core N-3-D 2 to 2.5 in.

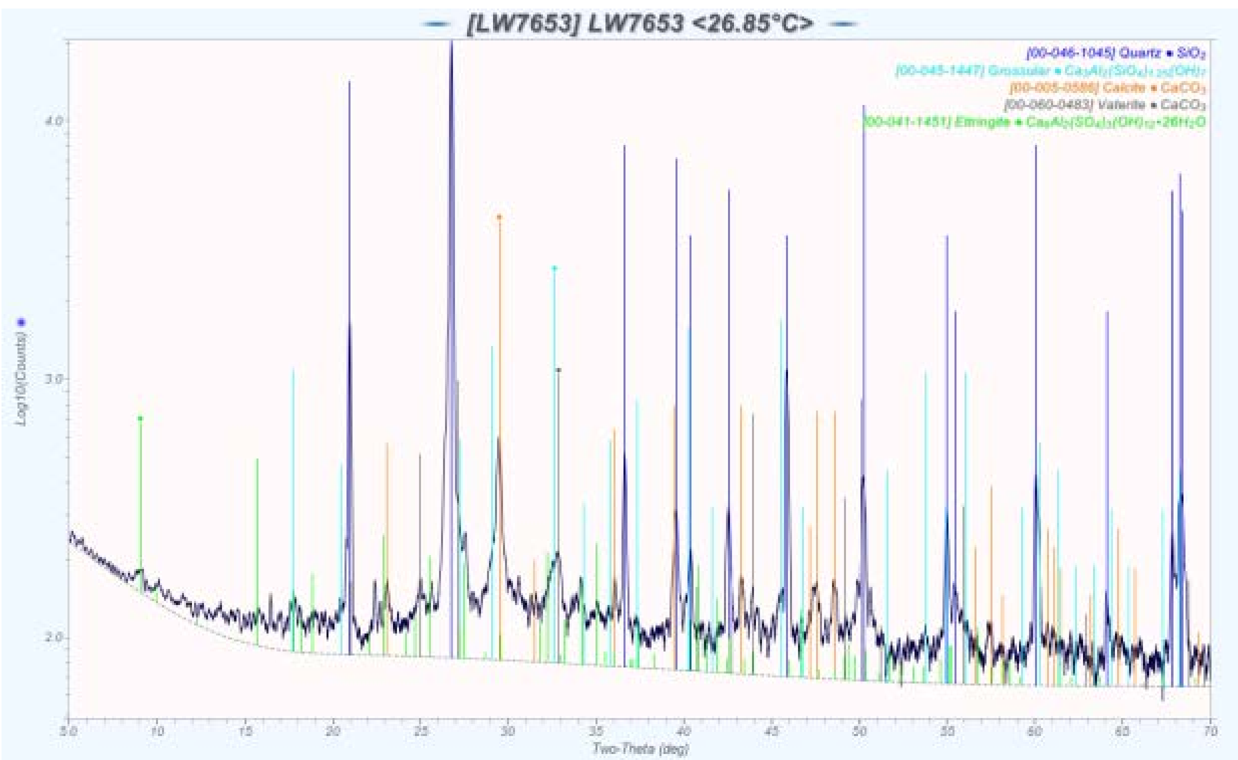


Figure C-16. XRD Pattern for Core N-3-D 2.5 to 3 in.

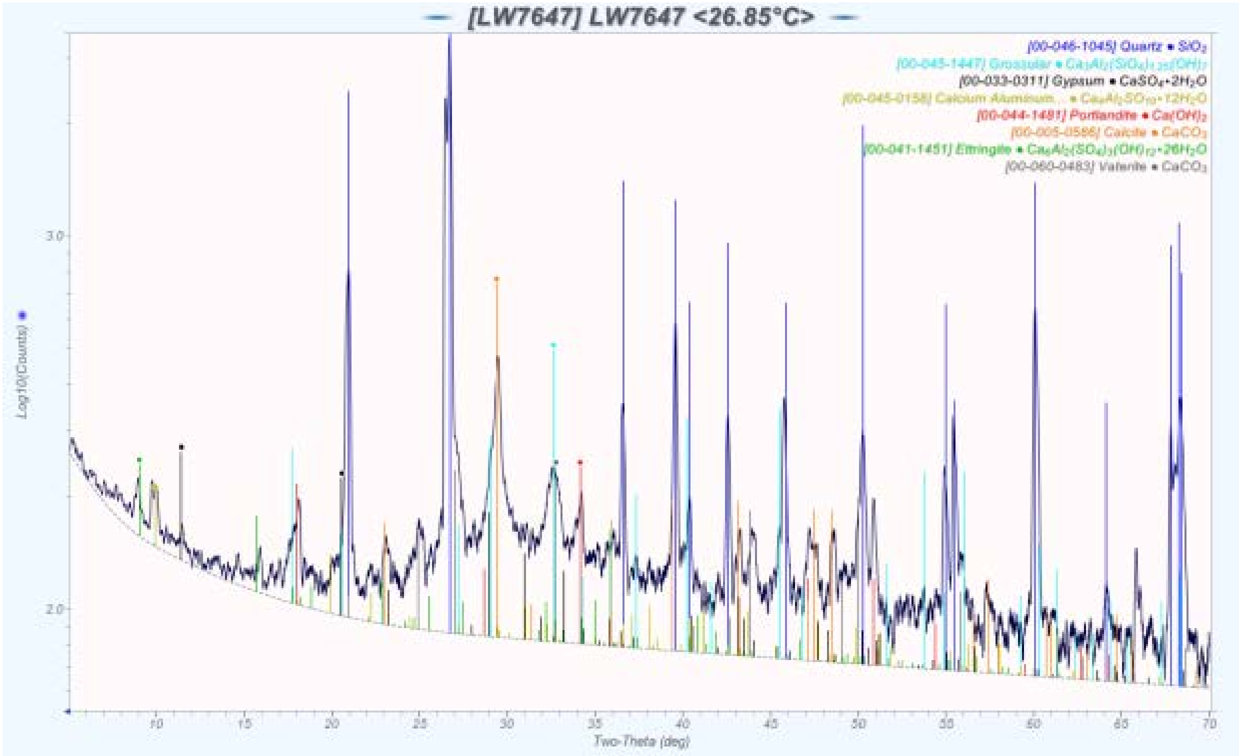


Figure C-17. XRD Pattern for Core N-3-D 3 to 4 in.

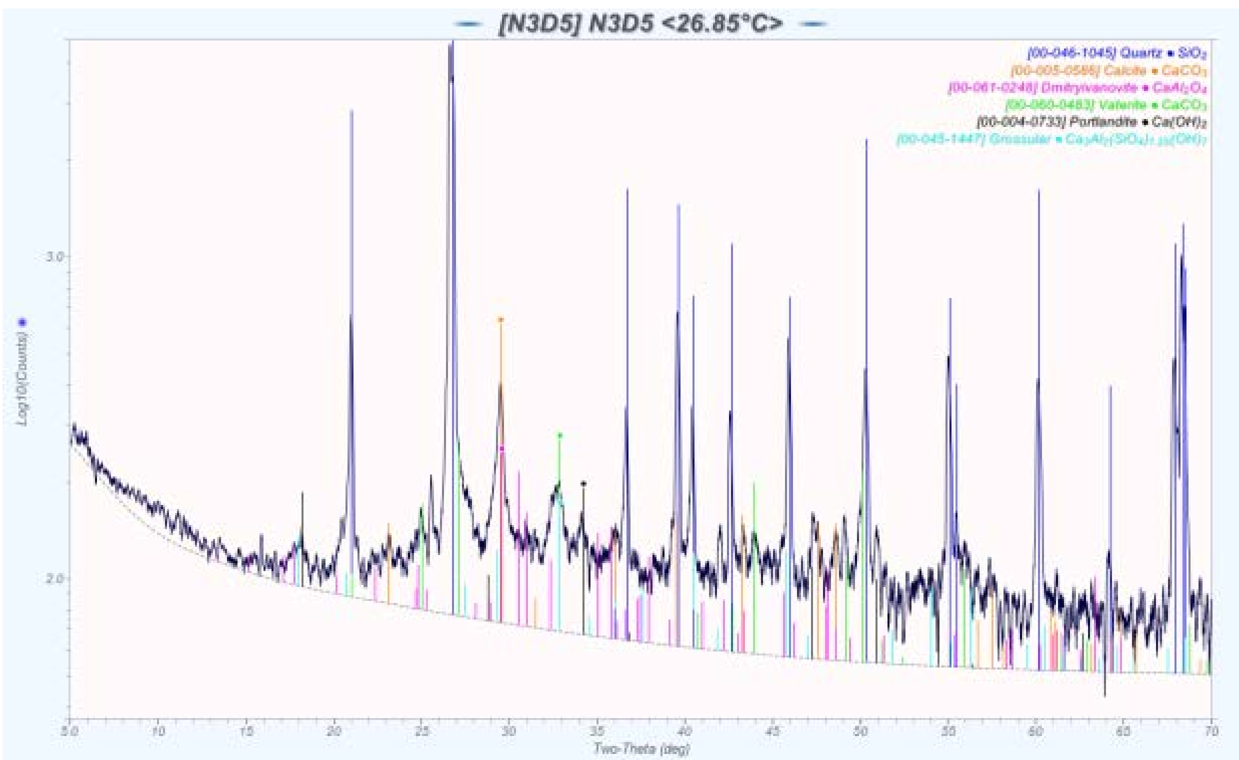


Figure C-18. XRD Pattern for Core N-3-D 5 inches.

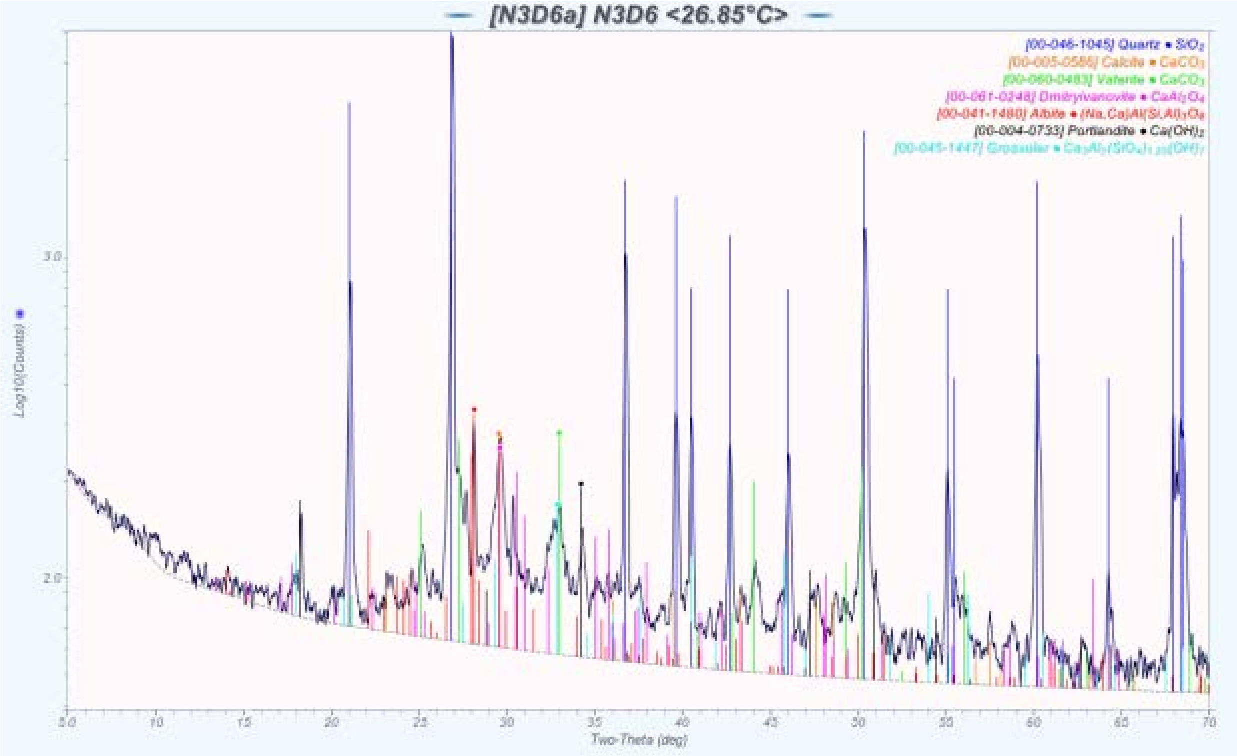


Figure C-19. XRD Pattern for Core N-3-D 6 inches.

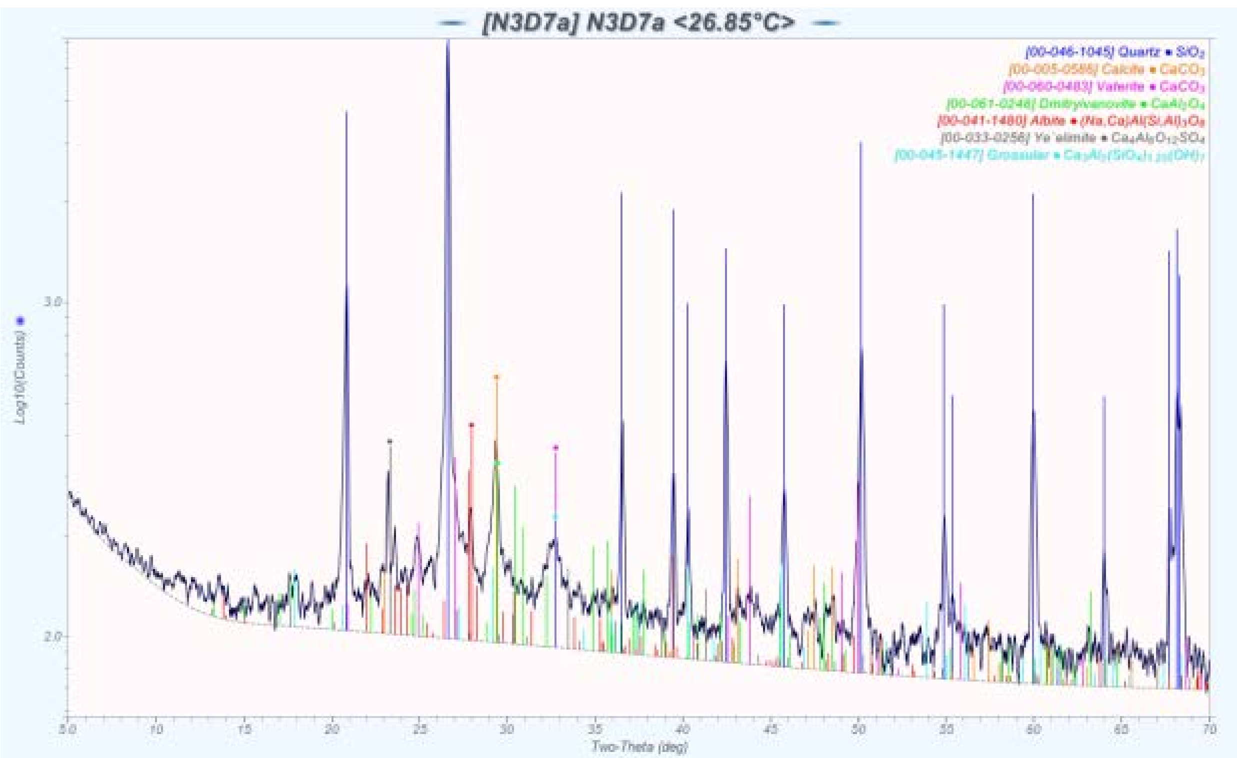


Figure C-20. XRD Pattern for Core N-3-D 7 inches.

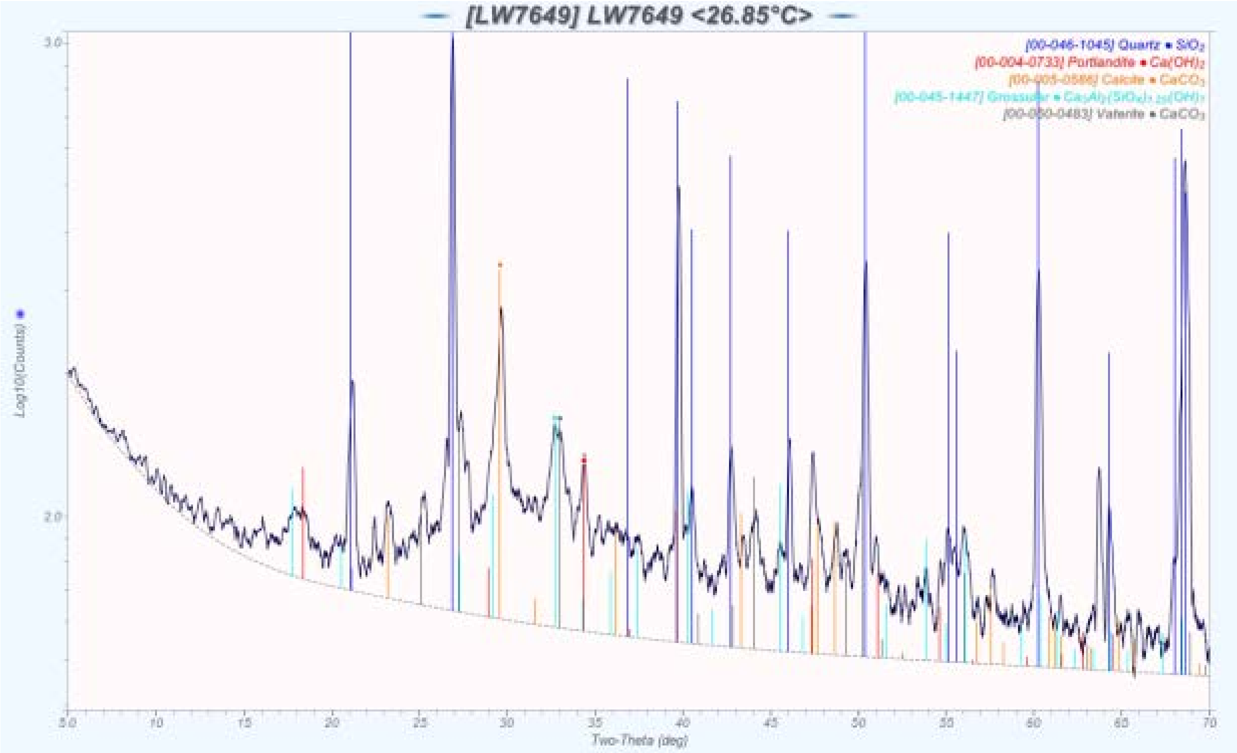


Figure C-21. XRD Pattern for Core N-3-D 6 to 7 in.

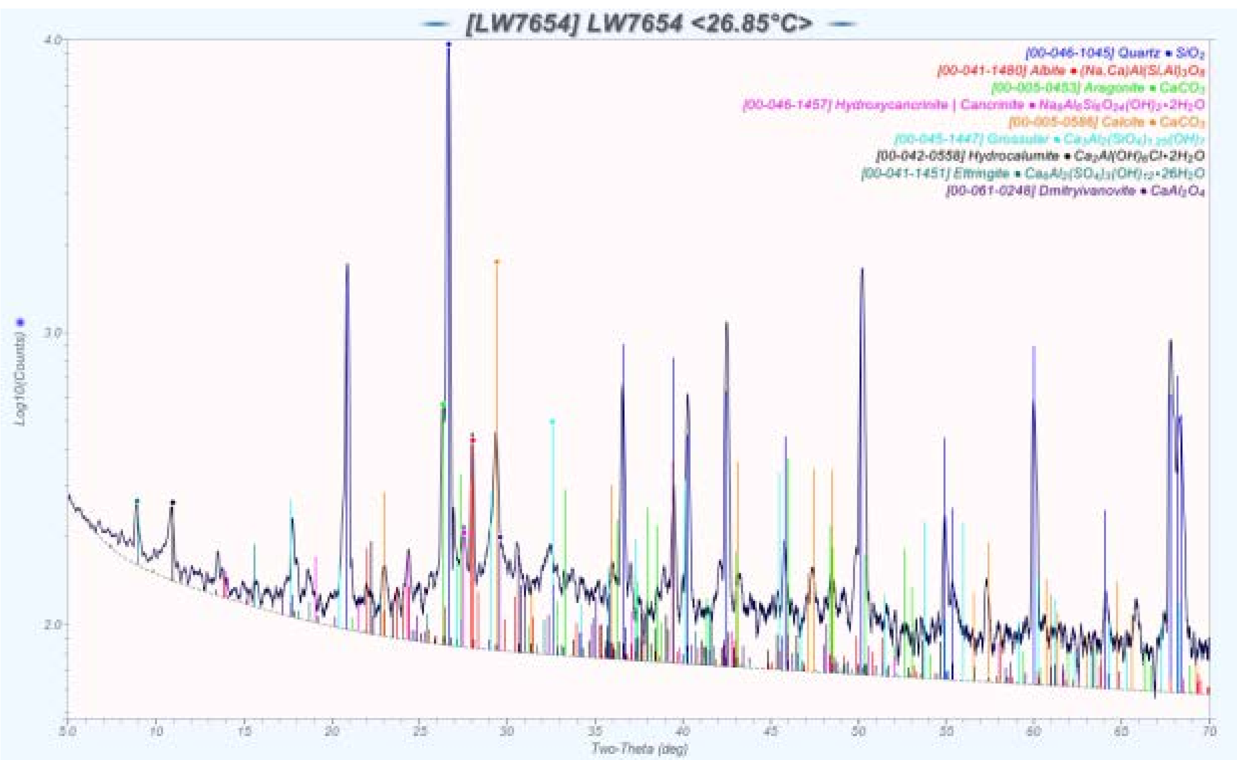


Figure C-22. XRD Pattern for Core N-4-D Surface.

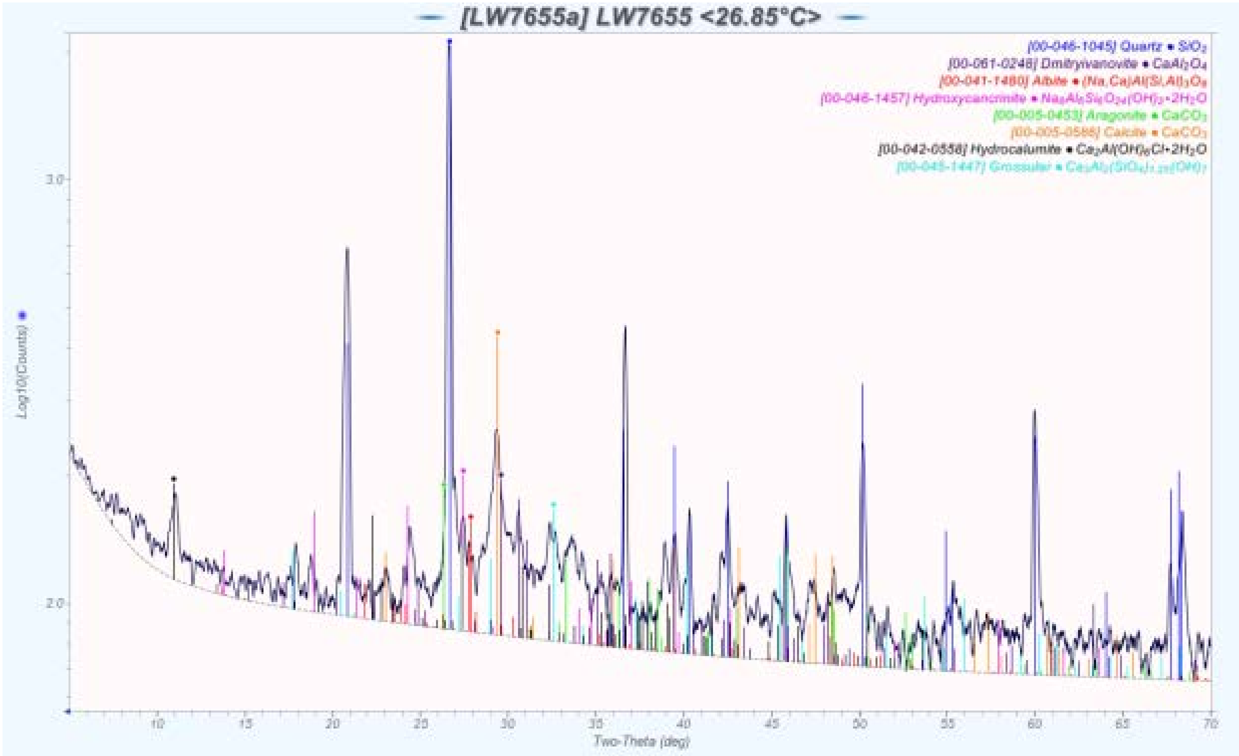


Figure C-23. XRD Pattern for Core N-4-D 0.5 inches.

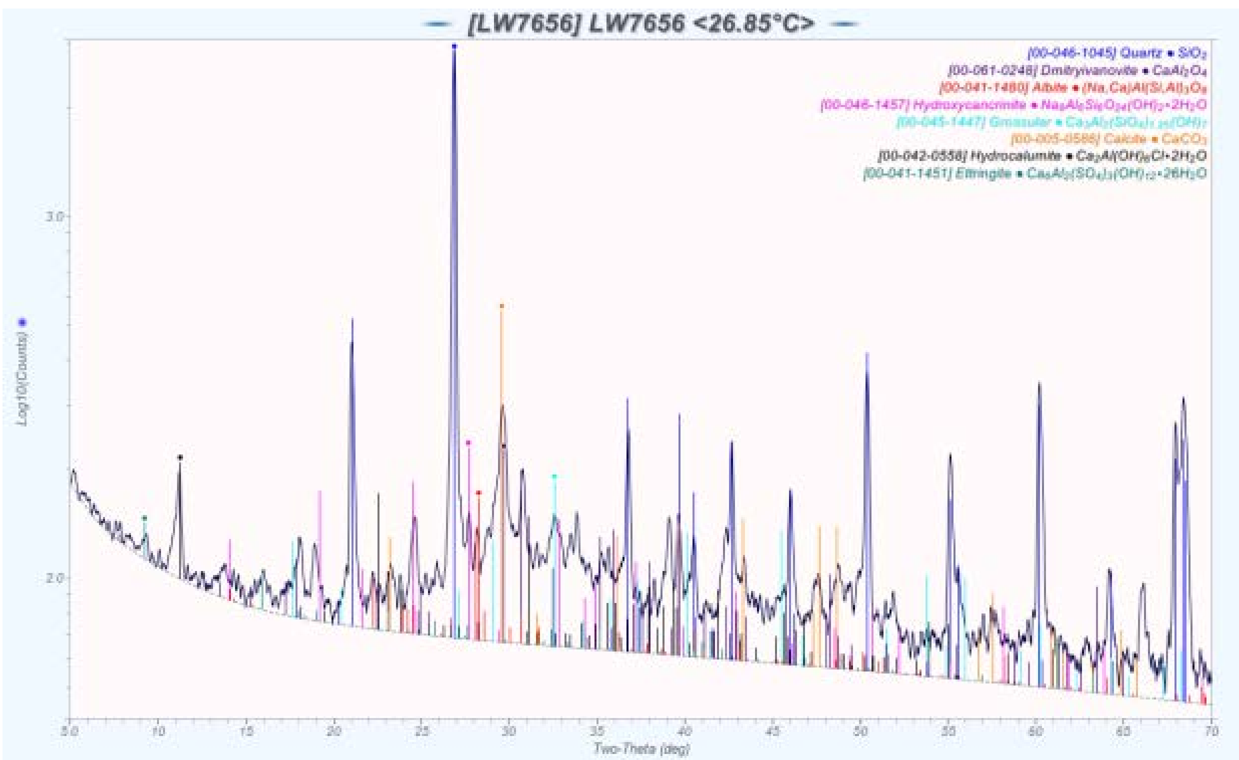


Figure C-24. XRD Pattern for Core N-4-D 1 inch.

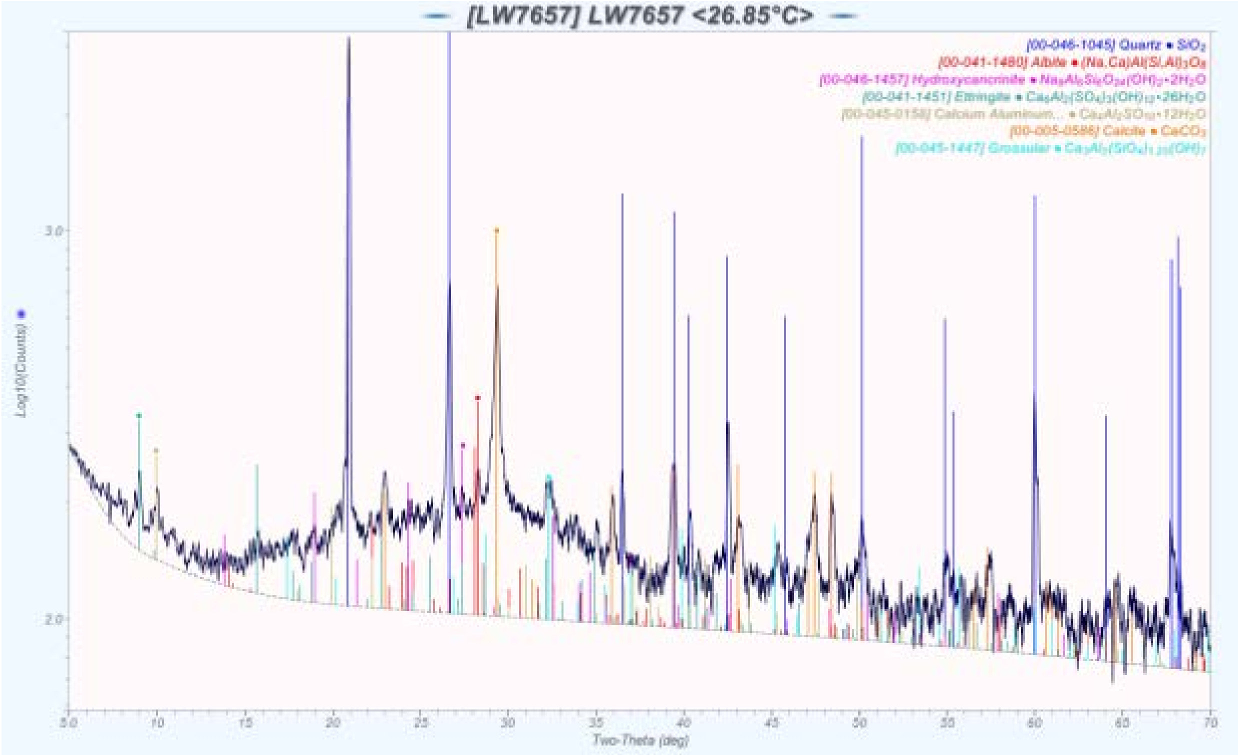


Figure C-25. XRD Pattern for Core N-4-D 1.5 inches.

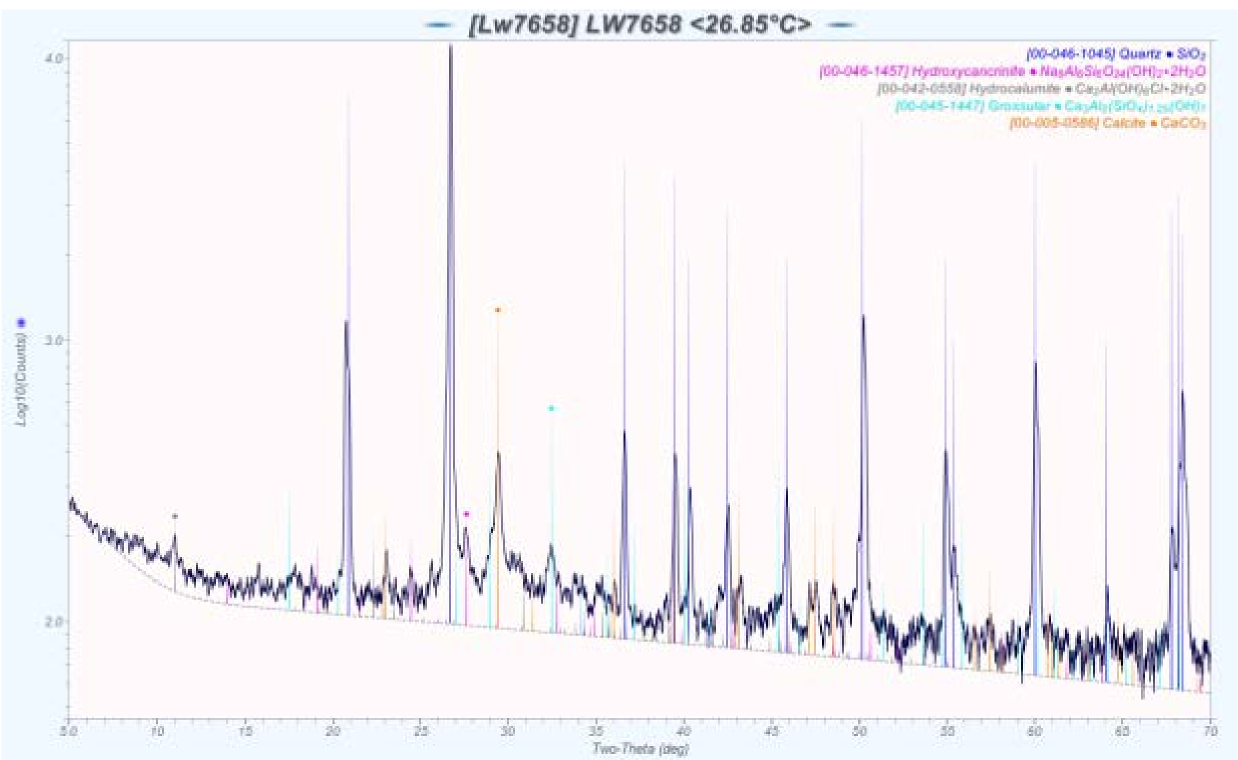


Figure C-26. XRD Pattern for Core N-4-D 2 inches.

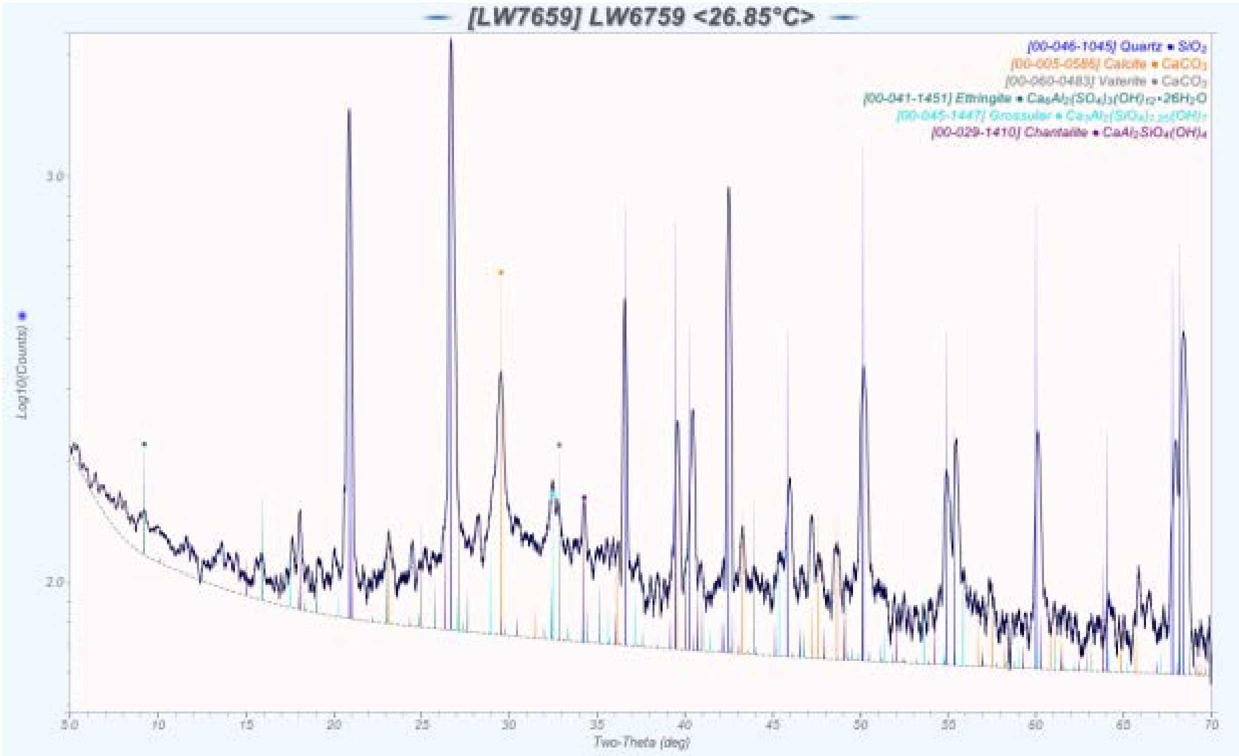


Figure C-27. XRD Pattern for Core N-4-D 2.5 inches.

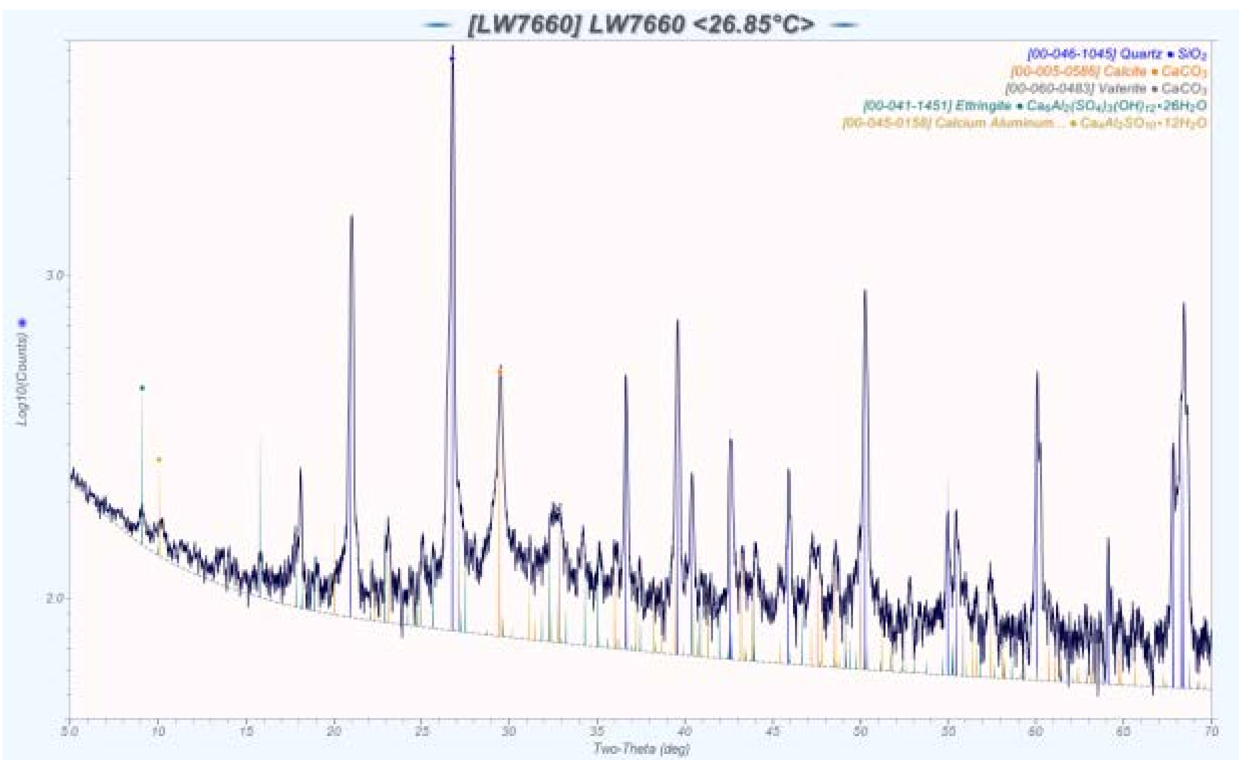


Figure C-28. XRD Pattern for Core N-4-D 3 inches.

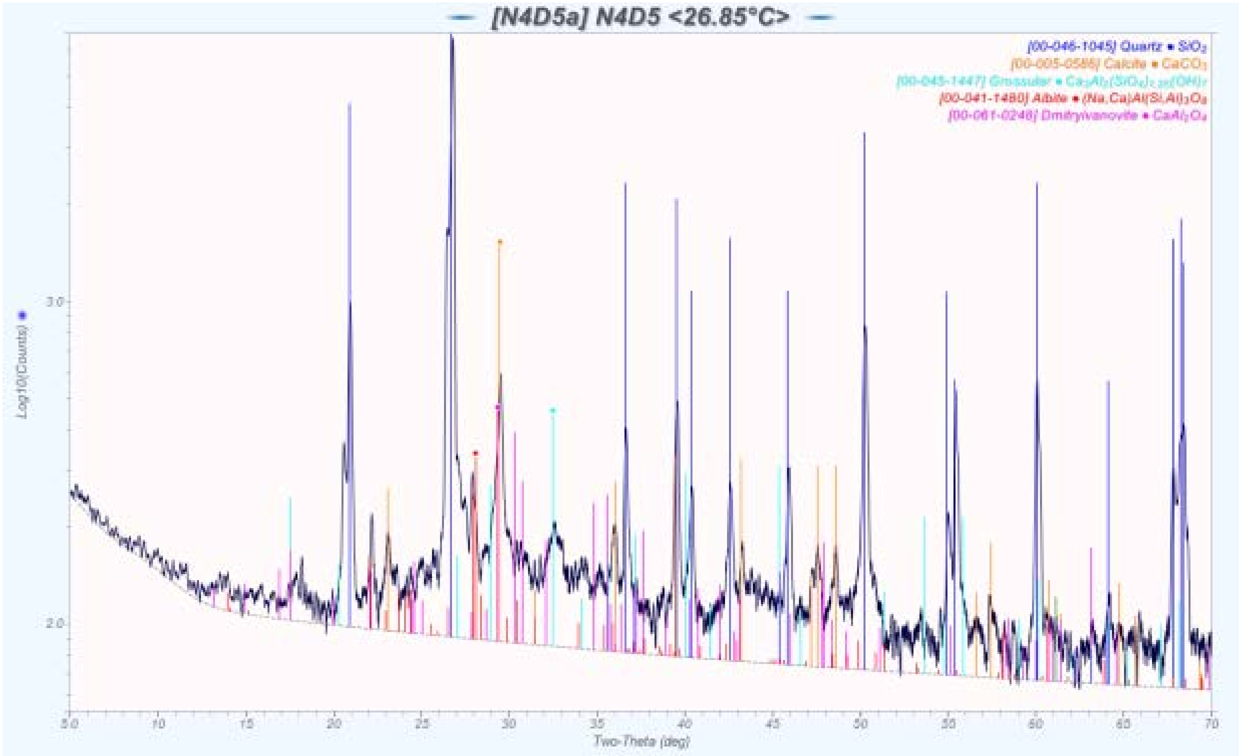


Figure C-29. XRD Pattern for Core N-4-D 5 inches.

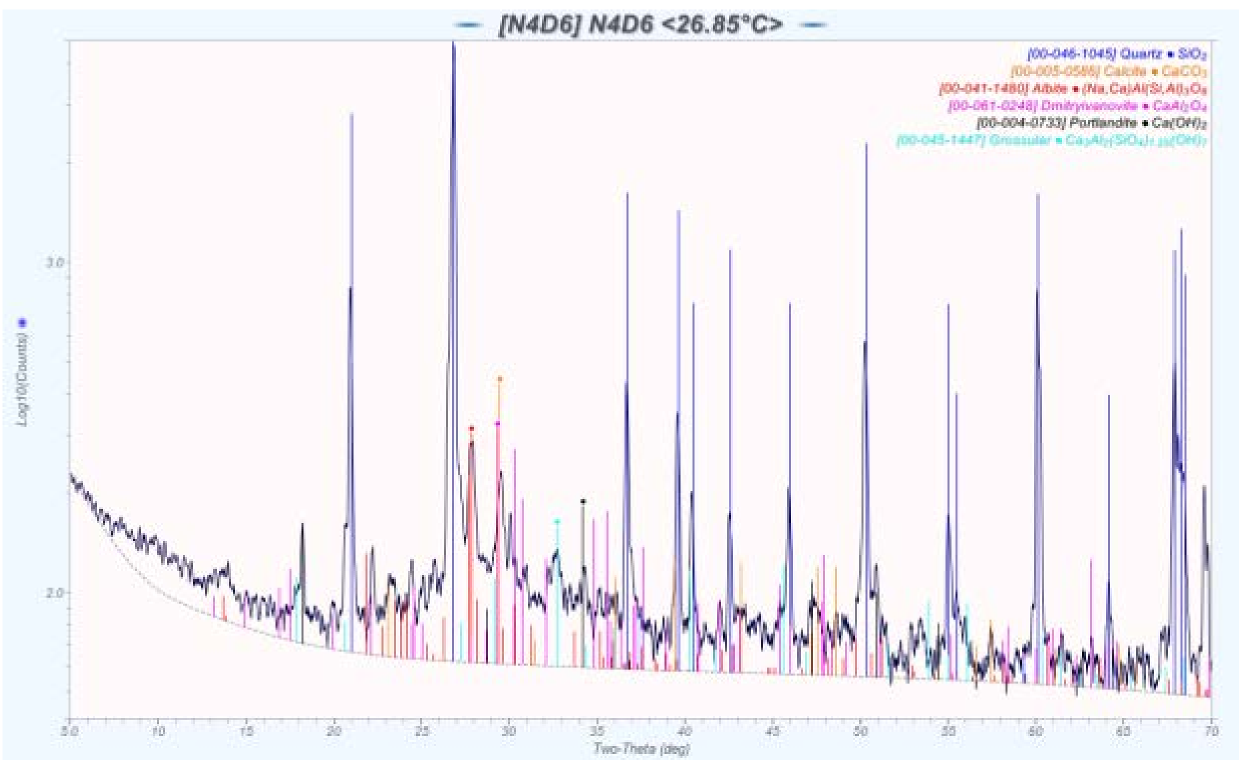


Figure C-30. XRD Pattern for Core N-4-D 6 inches.

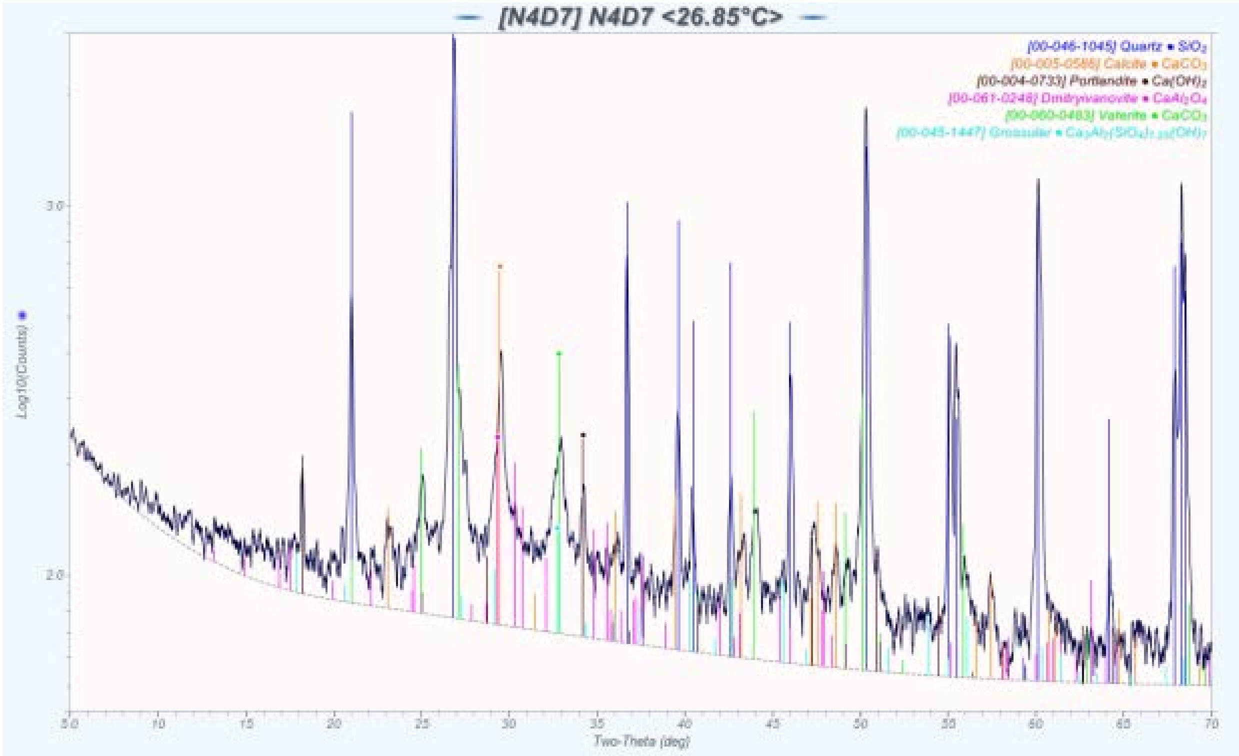


Figure C-31. XRD Pattern for Core N-4-D 7 inches.

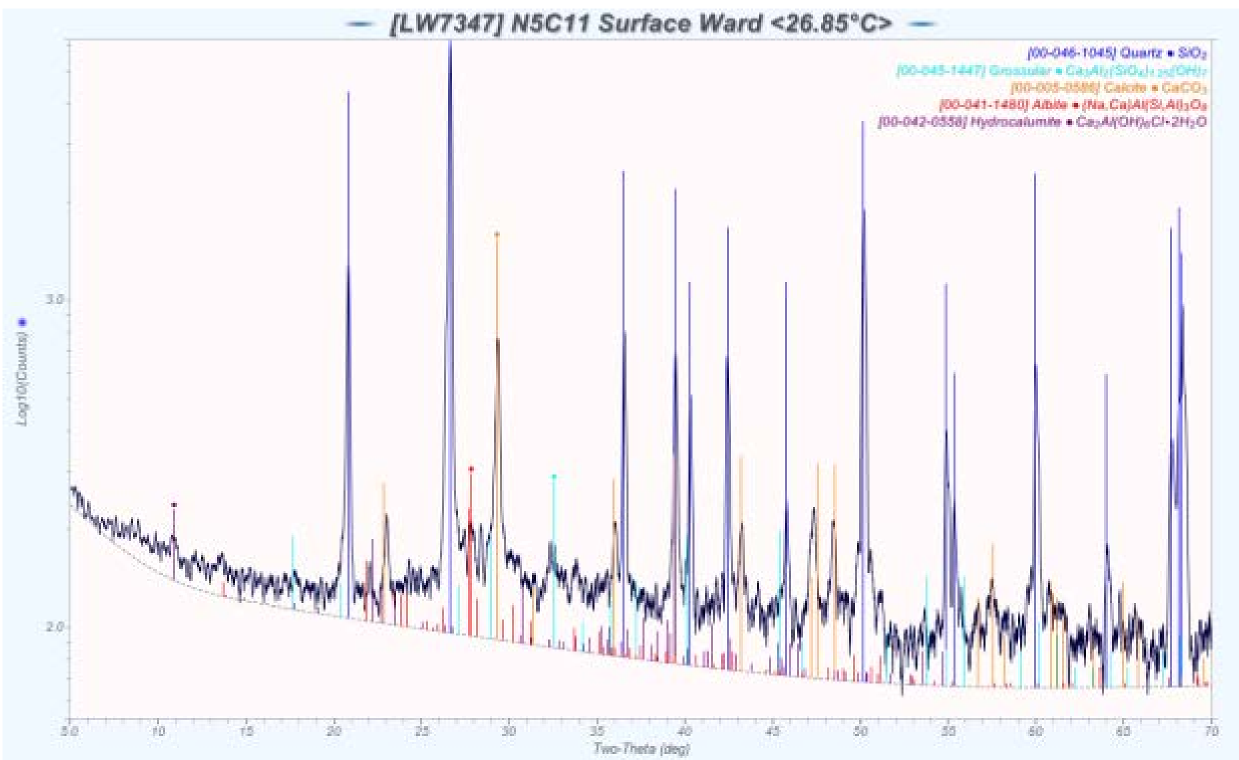


Figure C-32. XRD Pattern for Core N-5-C Surface.

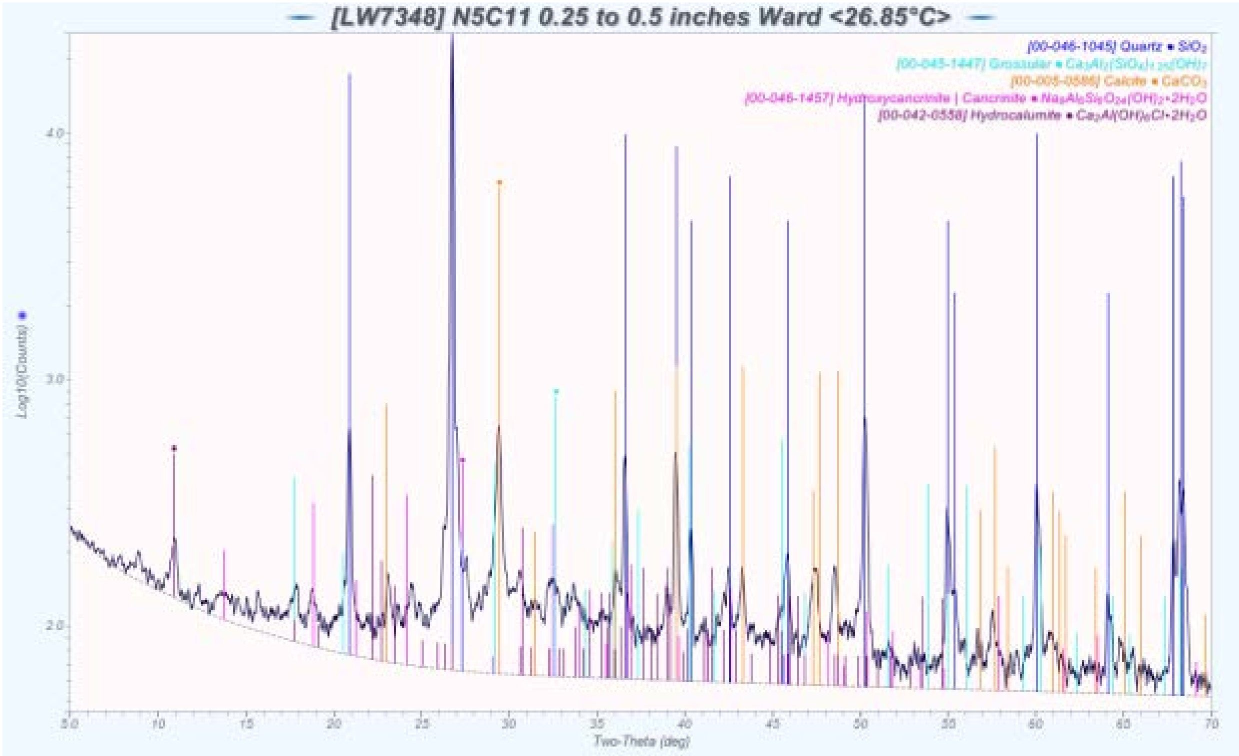


Figure C-33. XRD Pattern for Core N-5-C 0.25 to 0.5 inches.

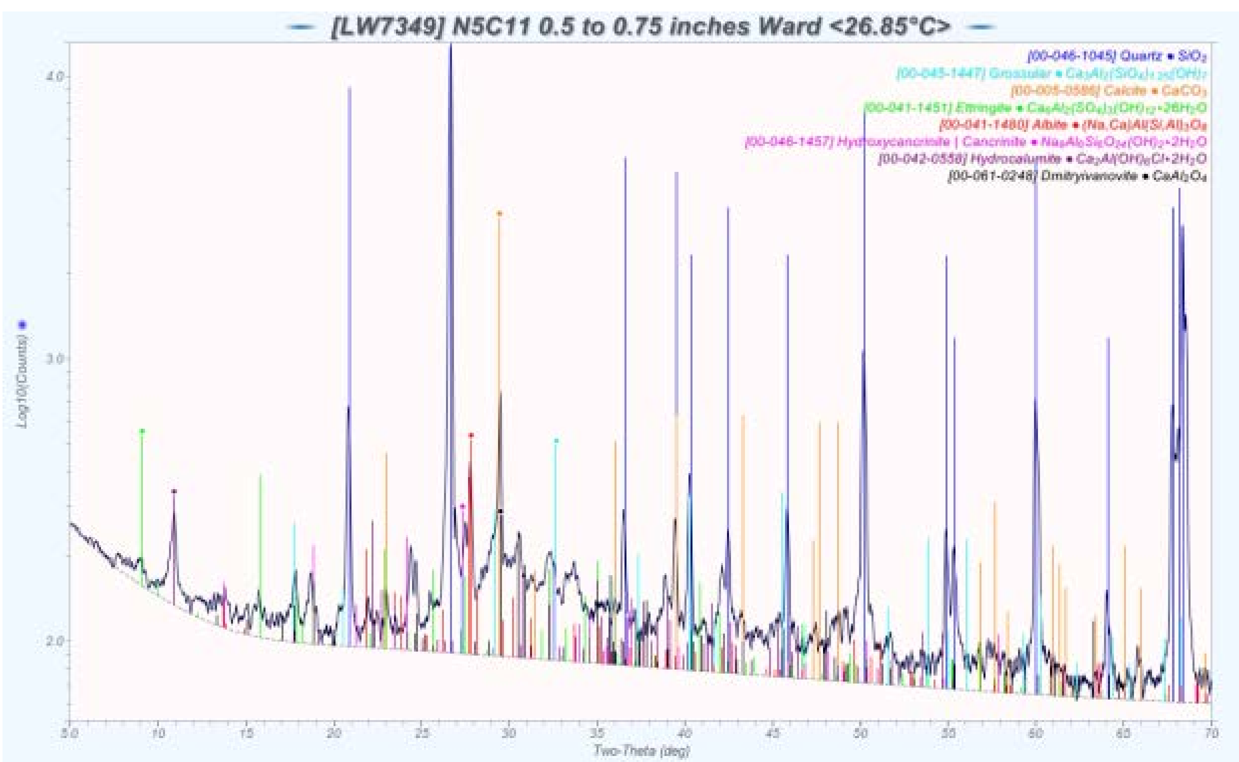


Figure C-34. XRD Pattern for Core N-5-C 0.5 to 0.75 inches.

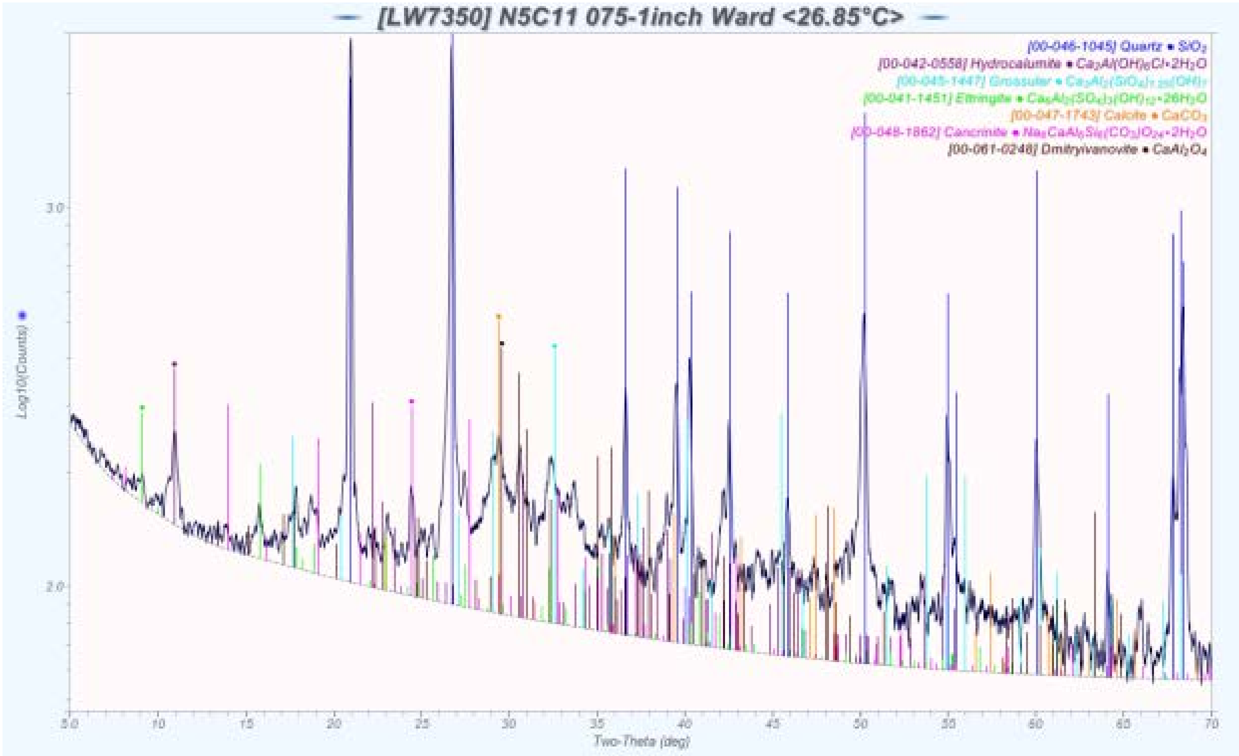


Figure C-35. XRD Pattern for Core N-5-C 0.75 to 1 inch.

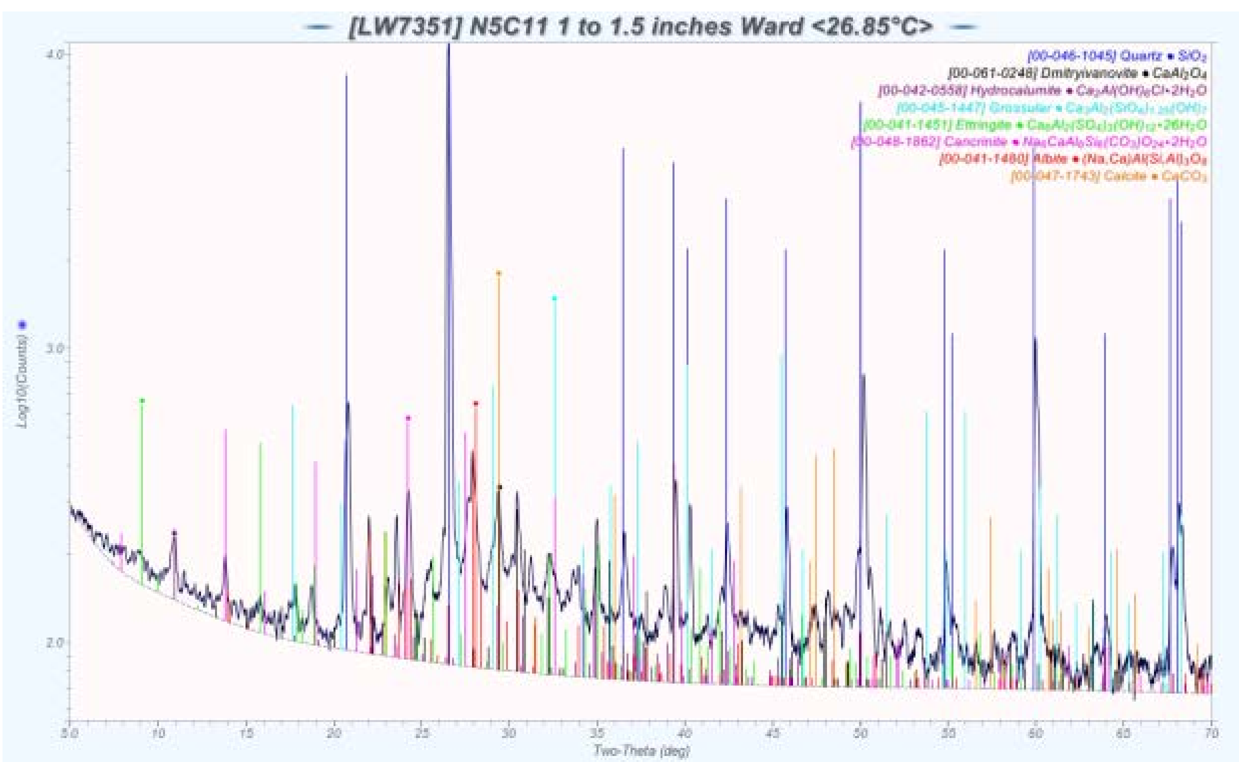


Figure C-36. XRD Pattern for Core N-5-C 1 to 1.5 inches.

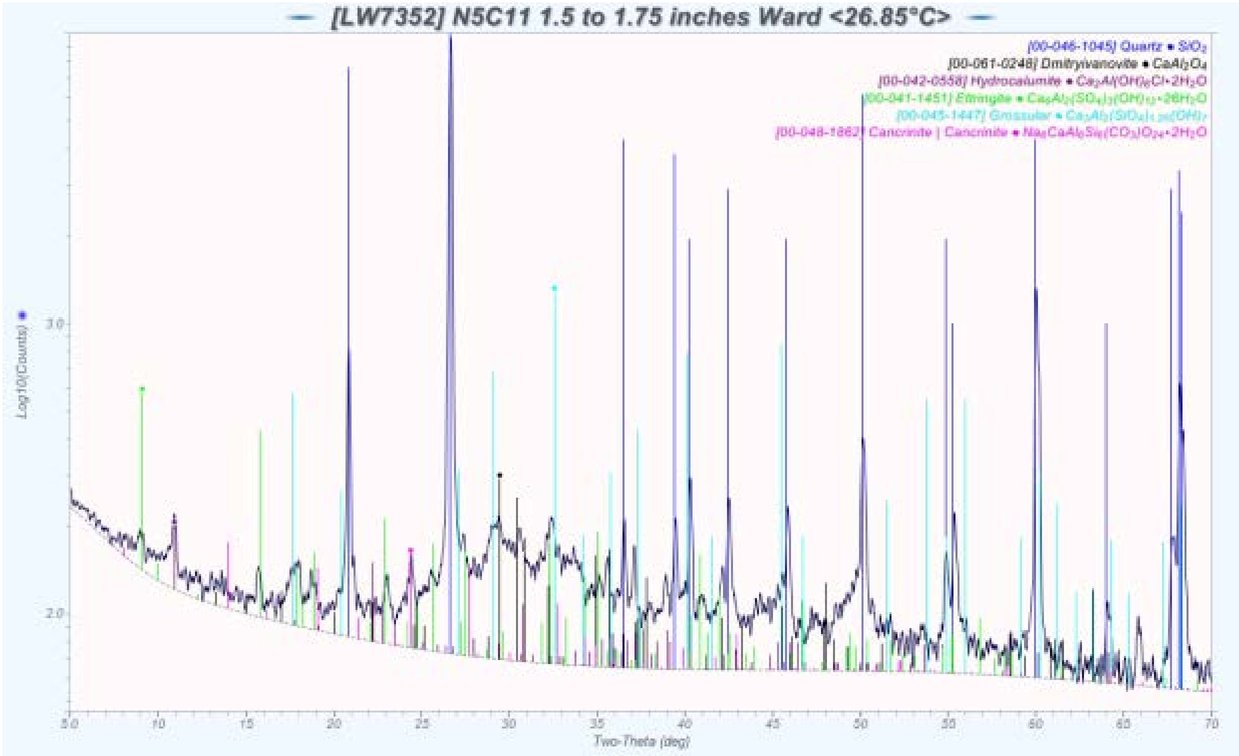


Figure C-37. XRD Pattern for Core N-5-C 1.5 to 1.75 inches.

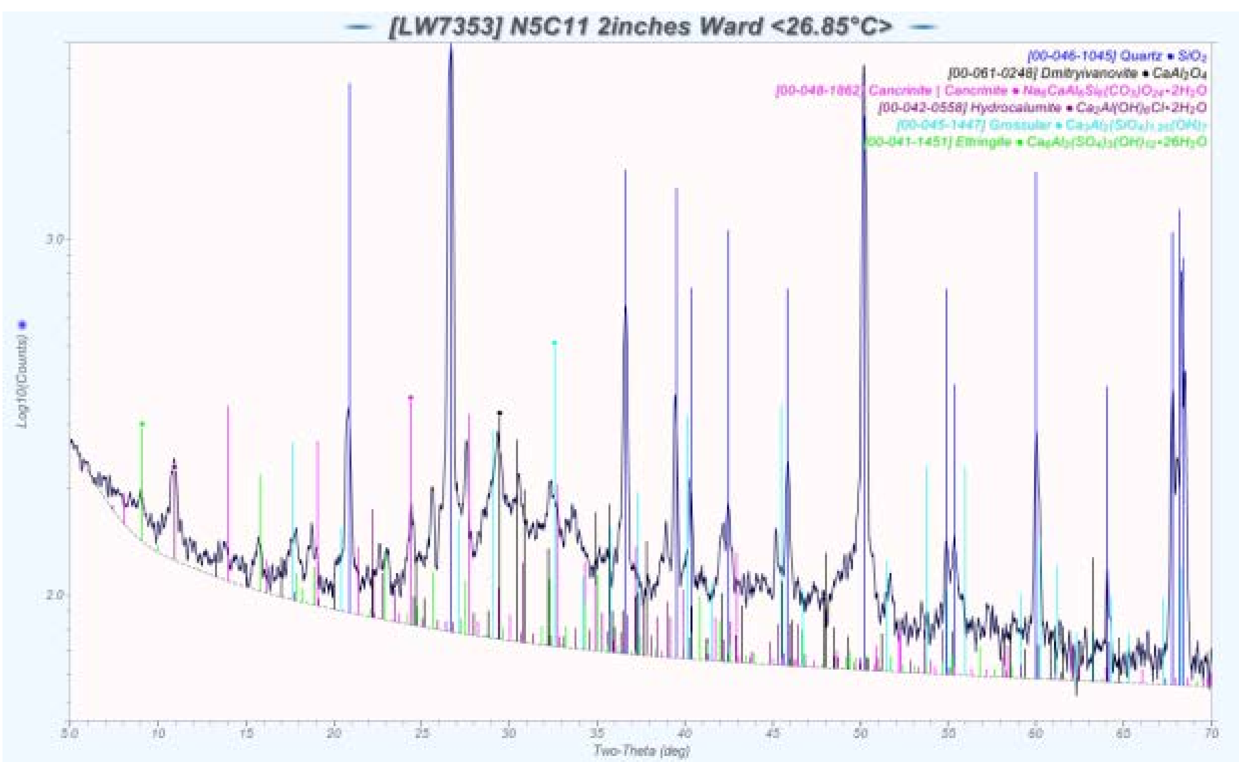


Figure C-38. XRD Pattern for Core N-5-C 2 inches.

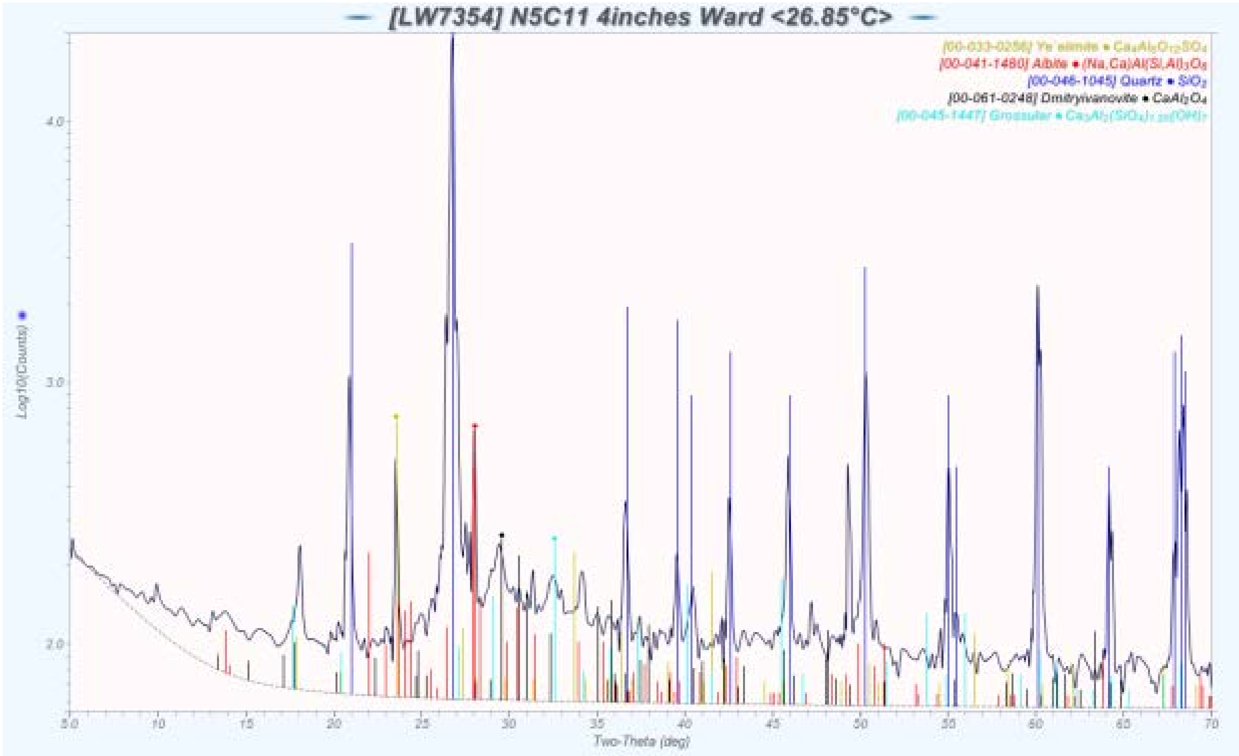


Figure C-39. XRD Pattern for Core N-5-C 4 inches.

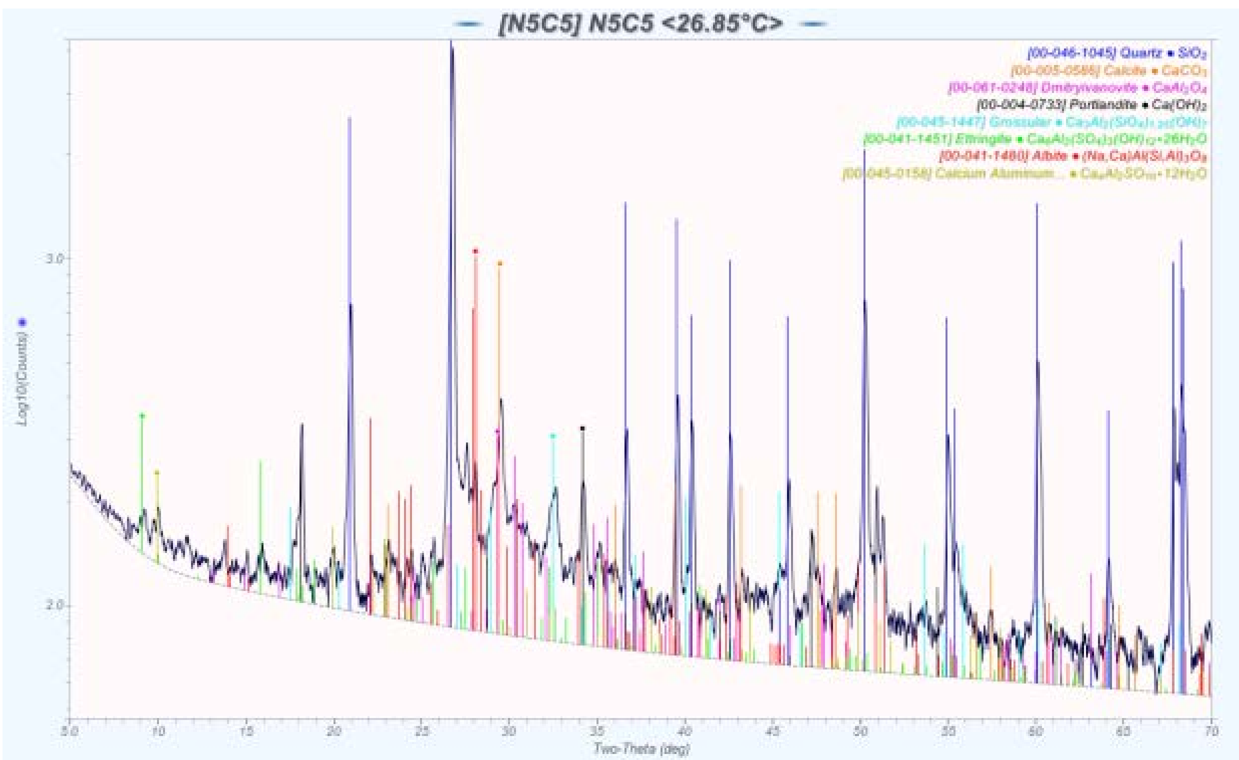


Figure C-40. XRD Pattern for Core N-5-C 5 inches.

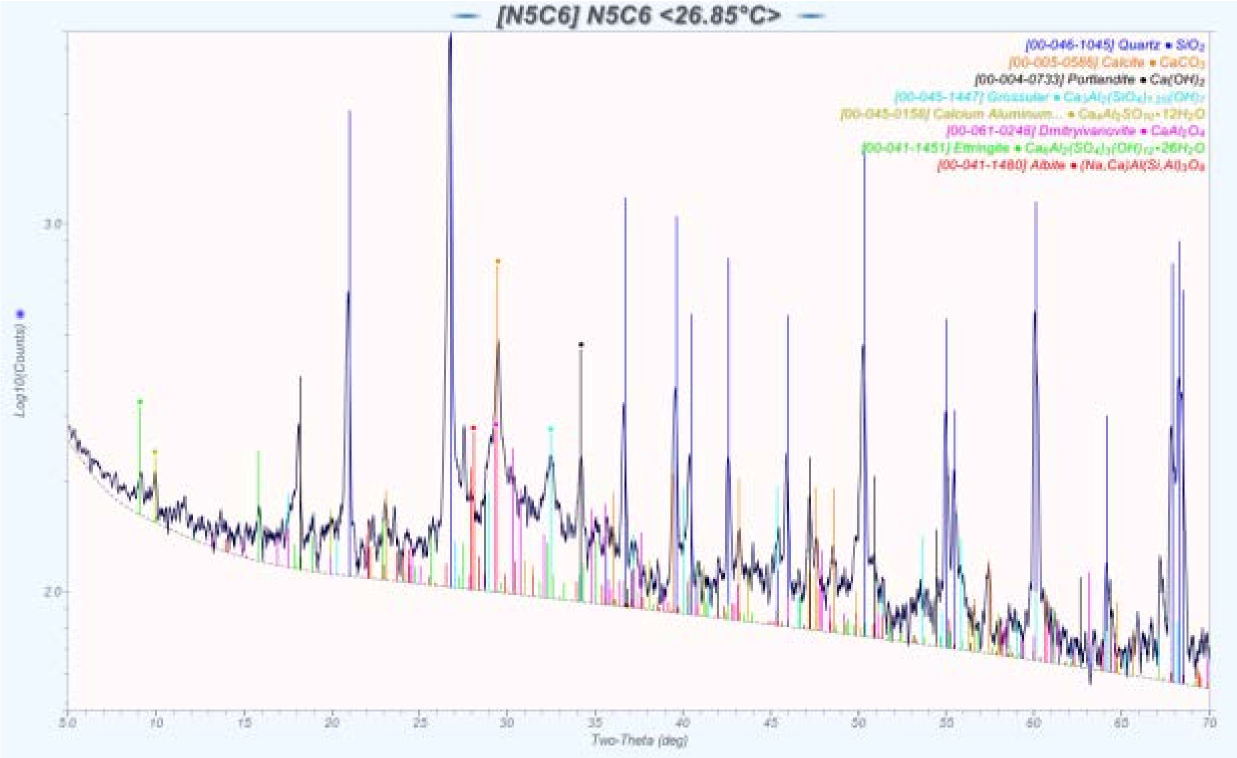


Figure C-41. XRD Pattern for Core N-5-C 6 inches.

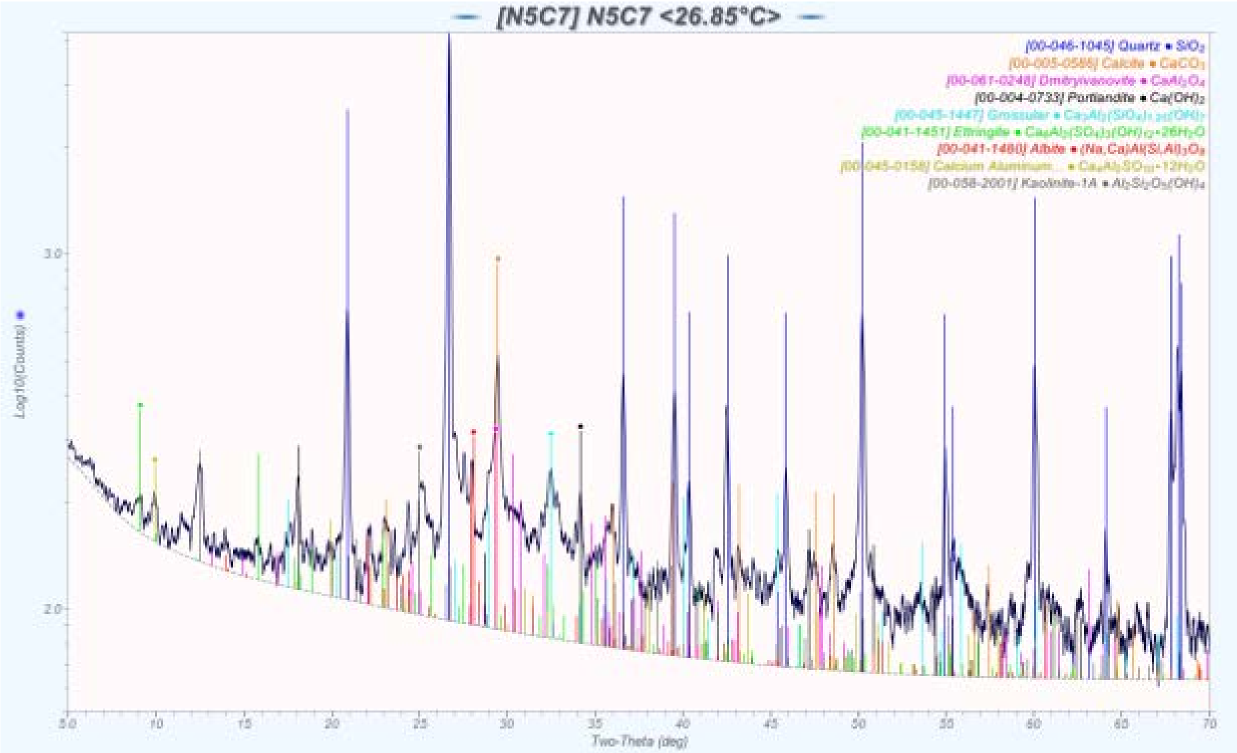


Figure C-42. XRD Pattern for Core N-5-C 7 inches.

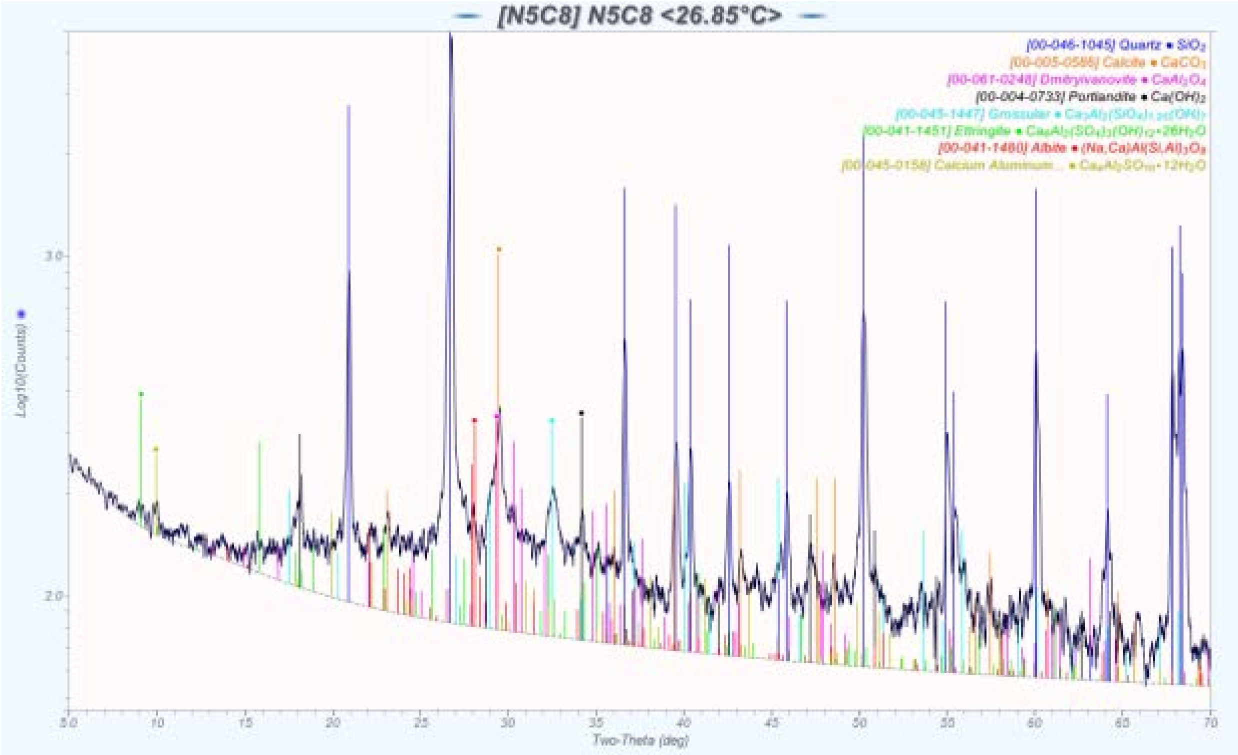


Figure C-43. XRD Pattern for Core N-5-C 8 inches.

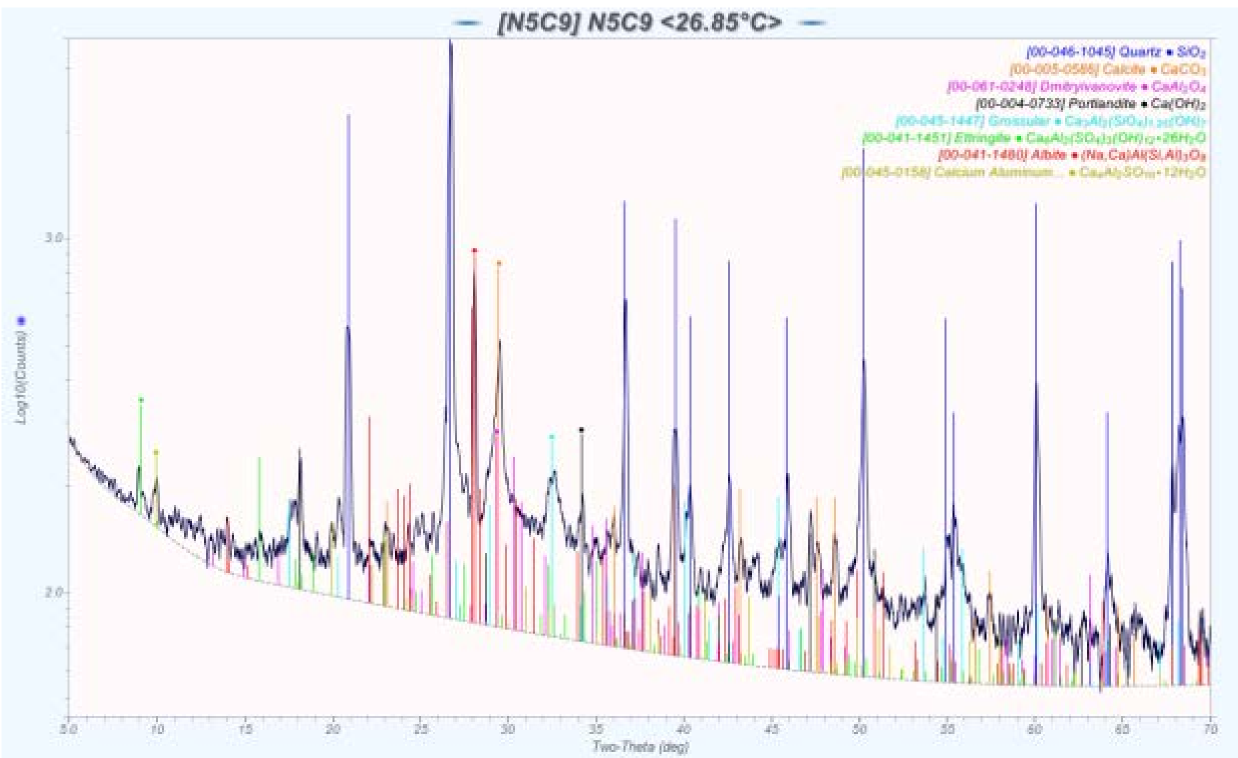


Figure C-44. XRD Pattern for Core N-5-C 9 inches.

Appendix D. Non-Radiologically Contaminated North Wall Concrete Cores - UPV Data Sheets

1/13/17 H area concrete

Rebar ~~em~~ embedded at position #3

PT3-S-4-CC	1	2	3	4	5	6	7	
Transmission Time	22.2 μs	21.4	22.1					
Distance	0.3098	0.310	0.3103					
Pulse Velocity	13964	14486	14027					
Compressive Strength								
E-Modulus								
Physical Measurement	3.717	3.720	3.724					
PT3-N-2-B	1	2	3	4	5	6	7	
Transmission Time	38.9	37.9	39.3	39.8	39.6	40.9	37.5	
Distance	0.473	0.473	0.474	0.4745	0.473	0.473	0.473	
Pulse Velocity	12159	12480	12092	11935	11944	11795	12613	
Compressive Strength								
E-Modulus								
Physical Measurement	5.675	5.680	5.689	5.694	5.680	5.670	5.675	
	8 ~~1~~	9 ~~2~~	10 ~~3~~	4	5	6	7	
Transmission Time	38.3	41.4	43.5					
Distance	0.473	0.473	0.472					
Pulse Velocity	12350	11425	10851					11964
Compressive Strength								
E-Modulus								
Physical Measurement	5.680	5.678	5.672					
PT3-N-1-B	1	2	3	4	5	6	7	
Transmission Time	25.7	22.5	22.5	22.5	22.9	23.8		
Distance	0.311	0.311	0.311	0.311	0.311	0.311		
Pulse Velocity	12101	13822	13822	13822	13463	13067		13349
Compressive Strength								
E-Modulus								
Physical Measurement	3.726	3.730	3.730	3.730	3.730	3.732		
	1	2	3	4	5	6	7	
Transmission Time								
Distance								
Pulse Velocity								
Compressive Strength								
E-Modulus								
Physical Measurement								
	1	2	3	4	5	6	7	
Transmission Time								
Distance								
Pulse Velocity								
Compressive Strength								
E-Modulus								
Physical Measurement								

1/13/17 H area concrete

Rebar ~~em~~ bedded at position #3

PT3-S-4-CC	1	2	3	4	5	6	7
Transmission Time	22.2 μs	21.4	22.1				
Distance	0.3098	0.310	0.3103				
Pulse Velocity	13964	14486	14027				
Compressive Strength							
E-Modulus							
Physical Measurement	3.717	3.720	3.724				

PT3-N-2-B	1	2	3	4	5	6	7
Transmission Time	38.9	37.9	39.3	39.8	39.6	40.9	37.5
Distance	0.473	0.473	0.474	0.4745	0.473	0.473	0.473
Pulse Velocity	12159	12480	12092	11935	11944	11795	12613
Compressive Strength							
E-Modulus							
Physical Measurement	5.675	5.680	5.689	5.694	5.680	5.670	5.675

	8	9	10	4	5	6	7	
Transmission Time	38.3	41.4	43.5					
Distance	0.473	0.473	0.472					
Pulse Velocity	12350	11425	10851					11964
Compressive Strength								
E-Modulus								
Physical Measurement	5.680	5.678	5.672					

PT3-N-1-B	1	2	3	4	5	6	7	
Transmission Time	25.7	22.5	22.5	22.5	22.9	23.8		
Distance	0.311	0.311	0.311	0.311	0.311	0.311		
Pulse Velocity	12101	13822	13822	13822	13463	13067		13349
Compressive Strength								
E-Modulus								
Physical Measurement	3.726	3.730	3.730	3.730	3.730	3.732		

	1	2	3	4	5	6	7
Transmission Time							
Distance							
Pulse Velocity							
Compressive Strength							
E-Modulus							
Physical Measurement							

	1	2	3	4	5	6	7
Transmission Time							
Distance							
Pulse Velocity							
Compressive Strength							
E-Modulus							
Physical Measurement							

Appendix E. Non-Radiologically Contaminated North Wall Concrete Cores - Compressive Strength, Porosity, and Density Data Sheets

ASR 18-203 (04/13)

URS
Savannah River Site

Summary Report of Testing Activities

☐ Report ☒ Cover Sheet

Approvals (If required)	Work Package No.: 1525456
Senior Civil Technician (Level III): Charles A. Bookhamer	QCIR No.: N/A Project No.: N/A
Civil Testing & Inspection Superintendent: W. Pope, Jr.	Design Category: CAB 1-11-17 ~~GS~~ SC Report No.: 2016-CAEX-0011 Date: 12-29-16
Lab. No.: 160104	Test Method: See attached pages
Discipline: Civil	Description: Concrete
Location: 221H Personnel Tunnel 3 North Wall	Reported to: J. Carter, 8-1727

Summary: This report presents the data required by the H-Area CAEX Tunnel Concrete Core Sampling Plan, C-ESR-H-00044, Revision 0. Page 2 contains a spreadsheet for data and results provided by the calculations of ASTM C642-13 covering the determination of density, percent absorption, and percent voids in hardened concrete.
Line 7 on page 2 references Sample ID 221H-PT3-N-1CC for this report.
See page 3 for the results of "Compressive Strength of Drilled Cores". Also note, the densities of the core segments are provided in the page 3 Remarks Section.
All information in this report is from core segments from sample location ~~221H-PT3-S-1.~~ 221H-PT3-N-1. 8-22-17 W.P.

N/A

M&TE: See attached pages	Cal. Due Date: See attached pages	Procedure: C-QCP-002
NCR No.: N/A		Rev.: 0
Test Results: ☐ Conforming ☐ Nonconforming ☒* N/A		PCN(s): N/A
Remarks: * For engineering evaluation N/A		Spec.: C-~~ERS~~ ESR-H-00044 1-12-17
		Rev.: 0
		DCF(s): N/A

Technician (Print/Sign): Charles A. Bookhamer/ Charles A. Bookhamer Level: III Date: 1-11-17

Reviewer (Print/Sign): Charles Z. Moore/ C. Z. Moore Level: II Date: 1-11-17

CZM 1-12-17 KM III 8-22-17

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8/22/17 1-12-17

ASR 18-250 (04/13)

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Savannah River Site

Summary Report of Testing Activities (Continuation Sheet)

Report Title: 221H Personnel Tunnel 3 North Wall **Report No.:** 2016-CAEX-0011

Item #	Summary

Density, Absorption, and Voids in Hardened Concrete

A = mass of oven-dried sample in air [g]
B = mass of surface-dry sample in air after immersion [g]
C = mass of surface-dry sample in air after immersion and boiling [g]
D = apparent mass of sample in water after immersion and boiling [g]
g_1 = bulk density, dry, Mg/m^3, or g/cm^3
g_2 = aparent bulk density, Mg/m^3, or g/cm^3
ρ = density of water = 1 Mg/m^3 = 1 g/cm^3

AAI = Absorption after immersion [%]
AAIB = Absorption after immersion and boiling [g]
g_1 = Bulk density, dry
BDAI = Bulk density after immersion
BDAIB = Bulk density after immersion and boiling
g_2 = Apparent Density
VPP = Volume of permeable pore speac (voids) [%]

Line	Sample ID	A [g]	B [g]	C [g]	D [g]	g_1 [g/cm^3]	g_2 [g/cm^3]	ρ [g/cm^3]	AAI [%]	AAIB [%]	BDAI [g/cm^3]	BDAIB [g/cm^3]	VPP [%]
1	*221H-PT3-N-6OC	1143.25	1243.83	1251.99	712.6	2.12	2.65	1.00	8.8	9.5	2.31	2.32	20.2
2	*221H-PT3-N- 5OC	1660.96	1797.27	1811.47	1034.2	2.14	2.65	1.00	8.2	9.1	2.31	2.33	19.4
3	221H-PT3-N-5BB	1676.66	1807.66	1822.62	1042.7	2.15	2.64	1.00	7.8	8.7	2.32	2.34	18.7
4	221H-PT3-N-4CC	2127.10	2295.52	2314.88	1324.2	2.15	2.65	1.00	7.9	8.8	2.32	2.34	19.0
5	*221H-PT3-N-4OC	959.79	1041.49	1051.06	597.5	2.12	2.65	1.00	8.5	9.5	2.30	2.32	20.1
6	221H-PT3-N-2CC	2871.57	3082.55	3110.20	1783.5	2.16	2.64	1.00	7.3	8.3	2.32	2.34	18.0
7	221H-PT3-N-1CC	1121.66	1205.50	1213.60	698.5	2.18	2.65	1.00	7.5	8.2	2.34	2.36	17.8

* Over Core

Absorption after immersion [%]	% = [(B-A)/A] X 100
Absorption after immersion and boiling [g]	% = [(C-A)/A] X 100
Bulk density, dry	g_1 = [A/(C-D)] X ρ
Bulk density after immersion	BDAI = [B/(C-D)] X ρ
Bulk density after immersion and boiling	BDAIB = [C/(C-D)] X ρ
Apparent Density	g_2 = [A/(A-D)] X ρ
Volume of permeable pore space (voids) [%]	% = (g_2 - g_1)/g_2 x 100

Comments: N/A

1-12-17

ASR 18-202 (4/13)

URS
Savannah River Site
Compressive Strength of Drilled Cores

ASTM C 39- (14) ASTM C 42-(13) ASTM C 617-(12)

Report No.: 2016-CAEX-0011 Project No.: N/A Work Package No.: 1525456 Design Cat.: SC

QCIR No.: N/A Date & Time Core Taken: 12-29-16 @ N/A Concrete Supplier: N/A Placement Date: 1952

Placement Location: 221H- Section 3, Personnel Tunnel North Wall Mix Design: N/A Design Strength: 2500 psi @ N/A Days

Lab. Number	Days Aged	Date Tested	Length Before Capping, in.	Length After Capping, in.	Average Diameter, in.	Area, sq.in.	Total Load, lbs.	Length to Diameter Ratio	Correction Factor	Unit Load, psi	Corrected psi	Technician Init./Level
160104	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
N-1-A	5	1-3-17	7.16	7.36	3.73	10.93	27085	1.97	1.00	2480	2480	GS III
N-1-C	5	1-3-17	7.08	7.29	3.74	10.99	25094	1.95	1.00	2280	2280	GS III
						N	A					

Direction of Application of the Load on the Specimen with Respect to the Horizontal Plane of the Concrete Placed: N/A

Nominal Maximum Size of Aggregate: N/A Method of Test: N/A

M&TE: 1) CA-002; 2) TM-5

Cal. Due Date: 1) 9-23-17; 2) 1-12-17

Test Results: ☐ Conforming ☐ Nonconforming ☒ *X N/A

NCR No.: N/A

Remarks: *For Engineering Evaluation. Density of Cores follows:
221H-PT3-N-1-A = 144 pcf; 221H-PT3-N-1-B = 143 pcf; 221H-PT3-N-1-C = 141 pcf;
Note, Sample 221H-PT3-N-1-B was given to SRNL for testing.

Procedure: C-QCP-002 Rev.: 0 PCN(s): N/A

Spec.: C-ESR-H-00044 Rev.: 0 DCF(s): N/A

Dwg(s): N/A Rev.: N/A DCF(s): N/A

Technician (Print/Sign): Glenn C. Spencer/ [signature] Level: III Date: 1-3-17

Reviewer (Print/Sign): Charles A. Bookhamer/ Charles A. Bookhamer Level: III Date: 1-11-17

1-12-17

ASR 18-203 (04/13)

URS
Savannah River Site
Summary Report of Testing Activities

☐ Report ☒ Cover Sheet

Page 1 of 3

Approvals (If required)	Work Package No.: 1525456
Senior Civil Technician (Level III): Charles A. Bookhamer	QCIR No.: N/A Project No.: N/A
Civil Testing & Inspection Superintendent: W. Pope, Jr.	Design Category: CAB 1-11-17 ~~GS~~ SC Report No.: 2016-CAEX-0010 Date: 12-27-16
Lab. No.: 160103	Test Method: See attached pages
Discipline: Civil	Description: Concrete
Location: 221H Personnel Tunnel 3 North Wall	Reported to: J. Carter, 8-1727

Summary: This report presents the data required by the H-Area CAEX Tunnel Concrete Core Sampling Plan, C-ESR-H-00044, Revision 0. Page 2 contains a spreadsheet for data and results provided by the calculations of ASTM C642-13 covering the determination of density, percent absorption, and percent voids in hardened concrete. Line 6 on page 2 references Sample ID 221H-PT3-N-2CC for this report.

See page 3 for the results of "Compressive Strength of Drilled Cores". Also note, the densities of the core segments are provided in the page 3 Remarks Section.

All information in this report is from core segments from sample location ~~221H-PT3-S-2.~~ 221H-PT3-N-2. 8-22-17 W.P.

N/A

M&TE: See attached pages	Cal. Due Date: See attached pages	Procedure: C-QCP-002	
NCR No.: N/A		Rev.: 0	
Test Results: ☐ Conforming ☐ Nonconforming ☒* N/A		PCN(s): N/A	
Remarks: * For engineering evaluation N/A		Spec.: C-~~ERS~~ ESR-H-00044 ACZ 1-12-17	
		Rev.: 0	
		DCF(s): N/A	

Technician (Print/Sign): Charles A. Bookhamer/ *Charles A. Bookhamer*	Level: III	Date: 1-11-17	
Reviewer (Print/Sign): Charles Z. Moore/ *C. Z. Moore* CZM 1-12-17	Level: II KM III 8-22-17	Date: 1-11-17	

THIS REPORT SHALL NOT BE REPRODUCED, EXCEPT IN FULL, WITHOUT THE WRITTEN APPROVAL OF THE LABORATORY. 1-12-17 8/22/17

ASR 18-250 (04/13)

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Savannah River Site

Summary Report of Testing Activities (Continuation Sheet)

Report Title: 221H Personnel Tunnel 3 North Wall **Report No.:** 2016-CAEX-0010

Item #	Summary

Density, Absorption, and Voids in Hardened Concrete

A = mass of oven-dried sample in air [g]
B = mass of surface-dry sample in air after immersion [g]
C = mass of surface-dry sample in air after immersion and boiling [g]
D = apparent mass of sample in water after immersion and boiling [g]
g_1 = bulk density, dry, Mg/m^3, or g/cm^3
g_2 = aparent bulk density, Mg/m^3, or g/cm^3
ρ = density of water = 1 Mg/m^3 = 1 g/cm^3

AAI = Absorption after immersion [%]
AAIB = Absorption after immersion and boiling [g]
g_1 = Bulk density, dry
BDAI = Bulk density after immersion
BDAIB = Bulk density after immersion and boiling
g_2 = Apparent Density
VPP = Volume of permeable pore speac (voids) [%]

Line	Sample ID	A [g]	B [g]	C [g]	D [g]	g_1 [g/cm³]	g_2 [g/cm³]	ρ [g/cm³]	AAI [%]	AAIB [%]	BDAI [g/cm³]	BDAIB [g/cm³]	VPP [%]
1	*221H-PT3-N-6OC	1143.25	1243.83	1251.99	712.6	2.12	2.65	1.00	8.8	9.5	2.31	2.32	20.2
2	*221H-PT3-N- 5OC	1660.96	1797.27	1811.47	1034.2	2.14	2.65	1.00	8.2	9.1	2.31	2.33	19.4
3	221H-PT3-N-5BB	1676.66	1807.66	1822.62	1042.7	2.15	2.64	1.00	7.8	8.7	2.32	2.34	18.7
4	221H-PT3-N-4CC	2127.10	2295.52	2314.88	1324.2	2.15	2.65	1.00	7.9	8.8	2.32	2.34	19.0
5	*221H-PT3-N-4OC	959.79	1041.49	1051.06	597.5	2.12	2.65	1.00	8.5	9.5	2.30	2.32	20.1
6	221H-PT3-N-2CC	2871.57	3082.55	3110.20	1783.5	2.16	2.64	1.00	7.3	8.3	2.32	2.34	18.0
7	221H-PT3-N-1CC	1121.66	1205.50	1213.60	698.5	2.18	2.65	1.00	7.5	8.2	2.34	2.36	17.8

* Over Core

Absorption after immersion [%]	% = [(B-A)/A] X 100
Absorption after immersion and boiling [g]	% = [(C-A)/A] X 100
Bulk density, dry	g_1 = [A/(C-D)] X ρ
Bulk density after immersion	BDAI = [B/(C-D)] X ρ
Bulk density after immersion and boiling	BDAIB = [C/(C-D)] X ρ
Apparent Density	g_2 = [A/(A-D)] X ρ
Volume of permeable pore space (voids) [%]	% = (g_2 - g_1)/g_2 x 100

Comments: N/A

THIS REPORT SHALL NOT BE REPRODUCED, EXCEPT IN FULL, WITHOUT THE WRITTEN APPROVAL OF THE LABORATORY.

1-12-17

ASR 18-202 (4/13)

URS

Savannah River Site

Compressive Strength of Drilled Cores

ASTM C 39- (14) ASTM C 42-(13) ASTM C 617-(12)

Report No.: 2016-CAEX-0010 Project No.: N/A Work Package No.: 1525456 Design Cat.: SC

QCIR No.: N/A Date & Time Core Taken: 12-27-16 @ N/A Concrete Supplier: N/A Placement Date: 1952

Placement Location: 221H- Section 3, Personnel Tunnel North Wall Mix Design: N/A Design Strength: 2500 psi @ N/A Days

Lab. Number	Days Aged	Date Tested	Length Before Capping, in.	Length After Capping, in.	Average Diameter, in.	Area, sq.in.	Total Load, lbs.	Length to Diameter Ratio	Correction Factor	Unit Load, psi	Corrected psi	Technician Init./Level
160103	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
N-2-A	5	1-3-17	10.94	11.30	5.68	25.34	52790	1.99	1.00	2080	2080	GS III

N A

Direction of Application of the Load on the Specimen with Respect to the Horizontal Plane of the Concrete Placed: N/A

Nominal Maximum Size of Aggregate: N/A Method of Test: N/A

M&TE: 1) CA-002; 2) TM-5

Cal. Due Date: 1) 9-23-17; 2) 1-12-17

Test Results: ☐ Conforming ☐ Nonconforming ☒ *X N/A

NCR No.: N/A

Procedure: C-QCP-002 Rev.: 0 PCN(s): N/A

Spec.: C-ESR-H-00044 Rev.: 0 DCF(s): N/A

Dwg(s): N/A Rev.: N/A DCF(s): N/A

Remarks: *For Engineering Evaluation. Density of Cores follows:
221H-PT3-N-2-A = 140 pcf; 221H-PT3-N-2-B = 141 pcf;
Note, Sample 221H-PT3-N-2-B was given to SRNL for testing.

Technician (Print/Sign): Glenn C. Spencer/ [signature] Level: III Date: 1-3-17

Reviewer (Print/Sign): Charles A. Bookhamer/ Charles A. Bookhamer Level: III Date: 1-11-17

THIS REPORT SHALL NOT BE REPRODUCED, EXCEPT IN FULL, WITHOUT THE WRITTEN APPROVAL OF THE LABORATORY.

1-12-17

ASR 18-203 (03/17)

System|One
Savannah River Site

Summary Report of Testing Activities

☐ Report ☒ Cover Sheet Page 1 of 2

Approvals (If required)	Work Package No.: 1525456
Senior Civil Technician (Level III): ~~Glenn Spencer~~ KEVIN MILLER KM 4-6-17	QCIR No.: N/A
	Project No.: N/A
Civil Testing & Inspection Superintendent: W. Pope, Jr.	Design Category: ~~GS~~ SC
	Report No.: 2017-CAEX-0003 Date: 3-28-17

Lab. No.: 170020	Test Method: See attached page
Discipline: Civil	Description: Concrete
Location: 221H Personnel Tunnel 3 North Wall	Reported to: J. Carter, 8-1727

Summary: This report presents the data required by the H-Area CAEX Tunnel Concrete Core Sampling Plan, C-ESR-H-00044, Revision 0. See pages 2 , for the results of "Compressive Strength of Drilled Cores". Also note, the densities of the core segments are provided in the pages 2 This report presents the data required by the H-Area CAEX Tunnel Concrete Core Sampling Plan,

All INFORMATION IN THIS REPORT IS FROM CORE SEGMENTS FROM SAMPLE LOCATION 221H-PT3-N-3 8-22-17 W.P.

N
A

M&TE: See Attached Page	Cal. Due Date: See Attached Page	Procedure: C-QCP-002
NCR No.: N/A		Rev.: 0
Test Results: ☐ Conforming ☐ Nonconforming ☒* N/A		PCN(s): N/A
Remarks: * For enginnering evaluation		Spec.: C-ESR-H-00044
N/A		Rev.: 0
N/A		
N/A		DCF(s): N/A

Technician (Print/Sign): Glenn Spencer/ [signature]	Level: III	Date: 4-3-17
Reviewer (Print/Sign): Kevin Miller/ KEVIN MILLER KM 8-22-17	Level: III	Date: 4-6-17

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ASR 18-202 (03/17)

System|One
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Compressive Strength of Drilled Cores

ASTM C 39-(14) ASTM C 42-(13) ASTM C 617-(12)

Report No.: 2017-CAEX-0003 Project No.: N/A Work Package No.: 1525456 Design Cat.: ~~GS~~ SC 8-22-17 WP

QCIR No.: N/A Date & Time Core Taken: 3-28-17 @ N/A Concrete Supplier: N/A Placement Date: 1952

Placement Location: 221H-PT3-N-3 Mix Design: N/A Design Strength: 2500 psi @ N/A Days

Lab. Number	Days Aged	Date Tested	Length Before Capping, in.	Length After Capping, in.	Average Diameter, in.	Area, sq.in.	Total Load, lbs.	Length to Diameter Ratio	Correction Factor	Unit Load, psi	Corrected psi	Technician Init./Level
170020	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3A	6	4-3-17	7.23	7.47	3.73	10.93	22734	2.00	1.00	2080	N/A	GS III
3B	6	4-3-17	7.15	7.33	3.73	10.93	22279	1.97	1.00	2040	N/A	GS III
						N/A						

Direction of Application of the Load on the Specimen with Respect to the Horizontal Plane of the Concrete Placed: N/A

Nominal Maximum Size of Aggregate: N/A Method of Test: N/A

M&TE: 1)CA-002, 2)TM-5

Cal. Due Date: 1)9-23-17, 2)1-11-18

Test Results: ☐ Conforming ☐ Nonconforming ☒ N/A

NCR No.: N/A

Remarks: *For Engineering Evaluation. Density of Cores follows:
221H-PT3-N-3-A = 142 pcf; 221H-PT3-N-3-B = 142 pcf;
N/A

Procedure: C-QCP-002 Rev.: 0 PCN(s): N/A

Spec.: C-ESR-H-00044 Rev.: 0 DCF(s): N/A

Dwg(s): N/A Rev.: N/A DCF(s): N/A

Technician (Print/Sign): Glenn Spencer/ Level: III Date: 4/3/17

Reviewer (Print/Sign): Kevin Miller/ KEVIN MILLER KM 8-22-17 Level: III Date: 4-6-17

THIS REPORT SHALL NOT BE REPRODUCED, EXCEPT IN FULL, WITHOUT THE WRITTEN APPROVAL OF THE LABORATORY. NJSM 4-11-17

ASR 18-203 (04/13)

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Savannah River Site

Summary Report of Testing Activities

☐ Report ☒ Cover Sheet Page 1 of 3

Approvals (If required)	Work Package No.: 1525456
Senior Civil Technician (Level III): Charles A. Bookhamer	QCIR No.: N/A Project No.: N/A
Civil Testing & Inspection Superintendent: W. Pope, Jr.	Design Category: CAB 1-11-17 ~~GS~~ SC Report No.: 2016-CAEX-0009 Date: 12-22-16
Lab. No.: 160102	Test Method: See attached pages
Discipline: Civil	Description: Concrete
Location: 221H Personnel Tunnel 3 North Wall	Reported to: J. Carter, 8-1727

Summary: This report presents the data required by the H-Area CAEX Tunnel Concrete Core Sampling Plan, C-ESR-H-00044, Revision 0. Page 2 contains a spreadsheet for data and results provided by the calculations of ASTM C642-13 covering the determination of density, percent absorption, and percent voids in hardened concrete. Line 4 on page 2 references Sample ID 221H-PT3-N-4CC and Line 5 on page 2 references Sample ID 221H-PT3-N-4OC for this report.

See page 3 for the results of "Compressive Strength of Drilled Cores". Also note, the densities of the core segments are provided in the page 3 Remarks Section.

All information in this report is from core segments and over core from sample location ~~221H-PT3-S-4~~ 221H-PT3-N-4. 8-22-17 W.P.

N/A

M&TE: See attached pages — Cal. Due Date: See attached pages	Procedure: C-QCP-002
NCR No.: N/A	Rev.: 0
Test Results: ☐ Conforming ☐ Nonconforming ☒* N/A	PCN(s): N/A
Remarks: * For engineering evaluation N/A	Spec.: C-~~ERS~~ ESR-H-00044 1-12-17
	Rev.: 0
	DCF(s): N/A

Technician (Print/Sign): Charles A. Bookhamer/ *Charles A. Bookhamer* Level: III Date: 1-11-17

Reviewer (Print/Sign): Charles Z. Moore/ *C Z M* Level: II Date: 1-11-17
CZM 1-12-17 KM III 8-22-17

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ASR 18-250 (04/13)

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Savannah River Site

Page 2 of 3

Summary Report of Testing Activities (Continuation Sheet)

Report Title: 221H Personnel Tunnel 3 North Wall **Report No.:** 2016-CAEX-0009

Item #	Summary

Density, Absorption, and Voids in Hardened Concrete

A = mass of oven-dried sample in air [g]
B = mass of surface-dry sample in air after immersion [g]
C = mass of surface-dry sample in air after immersion and boiling [g]
D = apparent mass of sample in water after immersion and boiling [g]
g_1 = bulk density, dry, Mg/m^3, or g/cm^3
g_2 = aparent bulk density, Mg/m^3, or g/cm^3
ρ = density of water = 1 Mg/m^3 = 1 g/cm^3

AAI = Absorption after immersion [%]
AAIB = Absorption after immersion and boiling [g]
g_1 = Bulk density, dry
BDAI = Bulk density after immersion
BDAIB = Bulk density after immersion and boiling
g_2 = Apparent Density
VPP = Volume of permeable pore speac (voids) [%]

		A	B	C	D	g_1	g_2	ρ	AAI	AAIB	BDAI	BDAIB	VPP
Line	Sample ID	[g]	[g]	[g]	[g]	[g/cm^3]	[g/cm^3]	[g/cm^3]	[%]	[%]	[g/cm^3]	[g/cm^3]	[%]
1	*221H-PT3-N-6OC	1143.25	1243.83	1251.99	712.6	2.12	2.65	1.00	8.8	9.5	2.31	2.32	20.2
2	*221H-PT3-N- 5OC	1660.96	1797.27	1811.47	1034.2	2.14	2.65	1.00	8.2	9.1	2.31	2.33	19.4
3	221H-PT3-N-5BB	1676.66	1807.66	1822.62	1042.7	2.15	2.64	1.00	7.8	8.7	2.32	2.34	18.7
4	221H-PT3-N-4CC	2127.10	2295.52	2314.88	1324.2	2.15	2.65	1.00	7.9	8.8	2.32	2.34	19.0
5	*221H-PT3-N-4OC	959.79	1041.49	1051.06	597.5	2.12	2.65	1.00	8.5	9.5	2.30	2.32	20.1
6	221H-PT3-N-2CC	2871.57	3082.55	3110.20	1783.5	2.16	2.64	1.00	7.3	8.3	2.32	2.34	18.0
7	221H-PT3-N-1CC	1121.66	1205.50	1213.60	698.5	2.18	2.65	1.00	7.5	8.2	2.34	2.36	17.8

* Over Core

Absorption after immersion [%]	% = [(B-A)/A] X 100
Absorption after immersion and boiling [g]	% = [(C-A)/A] X 100
Bulk density, dry	g_1 = [A/(C-D)] X ρ
Bulk density after immersion	BDAI = [B/(C-D)] X ρ
Bulk density after immersion and boiling	BDAIB = [C/(C-D)] X ρ
Apparent Density	g_2 = [A/(A-D)] X ρ
Volume of permeable pore space (voids) [%]	% = (g_2 - g_1)/g_2 x 100

Comments: N/A

THIS REPORT SHALL NOT BE REPRODUCED, EXCEPT IN FULL, WITHOUT THE WRITTEN APPROVAL OF THE LABORATORY.

1-12-17

ASR 18-202 (4/13)

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Compressive Strength of Drilled Cores

ASTM C 39- (14) ASTM C 42-(13) ASTM C 617-(12)

Report No.: 2016-CAEX-0009 Project No.: N/A Work Package No.: 1525456 Design Cat.: SC

QCIR No.: N/A Date & Time Core Taken: 12-22-16 @ N/A Concrete Supplier: N/A Placement Date: 1952

Placement Location: 221H- Section 3, Personnel Tunnel North Wall Mix Design: N/A Design Strength: 2500 psi @ N/A Days

Lab. Number	Days Aged	Date Tested	Length Before Capping, in.	Length After Capping, in.	Average Diameter, in.	Area, sq.in.	Total Load, lbs.	Length to Diameter Ratio	Correction Factor	Unit Load, psi	Corrected psi	Technician Init./Level
160102	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
N-4-A	7	12-29-16	7.16	7.40	3.73	10.93	21068	1.98	1.00	1930	1930	GS III
N-4-B	7	12-29-16	7.24	7.44	3.73	10.93	23910	1.99	1.00	2190	2190	GS III
N-4-C	7	12-29-16	7.25	7.44	3.73	10.93	23495	1.99	1.00	2150	2150	GS III
						NA						

Direction of Application of the Load on the Specimen with Respect to the Horizontal Plane of the Concrete Placed: N/A

Nominal Maximum Size of Aggregate: N/A Method of Test: N/A

M&TE: 1) CA-002; 2) TM-5

Cal. Due Date: 1) 9-23-17; 2) 1-12-17

Test Results: ☐ Conforming ☐ Nonconforming ☒ *X N/A

NCR No.: N/A

Remarks: *For Engineering Evaluation. Density of Cores follows:
221H-PT3-N-4-A = 140 pcf; 221H-PT3-N-4-B = 140 pcf; 221H-PT3-N-4-C = 141 pcf;
N/A

Procedure: C-QCP-002 Rev.: 0 PCN(s): N/A

Spec.: C-ESR-H-00044 Rev.: 0 DCF(s): N/A

Dwg(s): N/A Rev.: N/A DCF(s): N/A

Technician (Print/Sign): Glenn C. Spencer/ Level: III Date: 12-29-16

Reviewer (Print/Sign): Charles A. Bookhamer/ Charles A. Bookhamer Level: III Date: 1-11-17

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1-12-17

ASR 18-203 (04/13)

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Savannah River Site

Summary Report of Testing Activities

☐ Report ☒ Cover Sheet

Approvals (If required)	Work Package No.: 1525456
Senior Civil Technician (Level III): Charles A. Bookhamer	QCIR No.: N/A Project No.: N/A
Civil Testing & Inspection Superintendent: W. Pope, Jr.	Design Category: CAB 1-11-17 ~~CS~~ SC Report No.: 2016-CAEX-0008 Date: 12-21-16
Lab. No.: 160101	Test Method: See attached pages
Discipline: Civil	Description: Concrete
Location: 221H Personnel Tunnel 3 North Wall	Reported to: J. Carter, 8-1727

Summary: This report presents the data required by the H-Area CAEX Tunnel Concrete Core Sampling Plan, C-ESR-H-00044, Revision 0. Page 2 contains a spreadsheet for data and results provided by the calculations of ASTM C642-13 covering the determination of density, percent absorption, and percent voids in hardened concrete. Line 2 on page 2 references Sample ID 221H-PT3-N-5OC and Line 3 on page 2 references Sample ID 221H-PT3-N-5BB for this report.

See page 3 for the results of "Compressive Strength of Drilled Cores". Also note, the densities of the core segments are provided in the page 3 Remarks Section.

All information in this report is from over core and core segments from sample location ~~221H-PT3-S-5~~ 221H-PT3-N-5. 8-22-17 W.P.

M&TE: See attached pages	Cal. Due Date: See attached pages	Procedure: C-QCP-002
NCR No.: N/A		Rev.: 0
Test Results: ☐ Conforming ☐ Nonconforming ☒* N/A		PCN(s): N/A
Remarks: * For engineering evaluation N/A		Spec.: C-~~ERS~~ ESR-H-00044 1-12-17
		Rev.: 0
		DCF(s): N/A

Technician (Print/Sign): Charles A. Bookhamer/ Charles A. Bookhamer Level: III Date: 1-11-17

Reviewer (Print/Sign): Charles Z. Moore/ C. Z. Moore Level: II Date: 1-11-17

CZM 1-12-17 KM III 8-22-17

THIS REPORT SHALL NOT BE REPRODUCED, EXCEPT IN FULL, WITHOUT THE WRITTEN APPROVAL OF THE LABORATORY. 1-12-17 8/22/17

ASR 18-250 (04/13)

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Savannah River Site

Summary Report of Testing Activities (Continuation Sheet)

Report Title: 221H Personnel Tunnel 3 North Wall **Report No.:** 2016-CAEX-0008

Item #	Summary

Density, Absorption, and Voids in Hardened Concrete

A = mass of oven-dried sample in air [g]
B = mass of surface-dry sample in air after immersion [g]
C = mass of surface-dry sample in air after immersion and boiling [g]
D = apparent mass of sample in water after immersion and boiling [g]
g_1 = bulk density, dry, Mg/m^3, or g/cm^3
g_2 = aparent bulk density, Mg/m^3, or g/cm^3
ρ = density of water = 1 Mg/m^3 = 1 g/cm^3

AAI = Absorption after immersion [%]
AAIB = Absorption after immersion and boiling [g]
g_1 = Bulk density, dry
BDAI = Bulk density after immersion
BDAIB = Bulk density after immersion and boiling
g_2 = Apparent Density
VPP = Volume of permeable pore speac (voids) [%]

Line	Sample ID	A [g]	B [g]	C [g]	D [g]	g_1 [g/cm^3]	g_2 [g/cm^3]	ρ [g/cm^3]	AAI [%]	AAIB [%]	BDAI [g/cm^3]	BDAIB [g/cm^3]	VPP [%]
1	*221H-PT3-N-6OC	1143.25	1243.83	1251.99	712.6	2.12	2.65	1.00	8.8	9.5	2.31	2.32	20.2
2	*221H-PT3-N- 5OC	1660.96	1797.27	1811.47	1034.2	2.14	2.65	1.00	8.2	9.1	2.31	2.33	19.4
3	221H-PT3-N-5BB	1676.66	1807.66	1822.62	1042.7	2.15	2.64	1.00	7.8	8.7	2.32	2.34	18.7
4	221H-PT3-N-4CC	2127.10	2295.52	2314.88	1324.2	2.15	2.65	1.00	7.9	8.8	2.32	2.34	19.0
5	*221H-PT3-N-4OC	959.79	1041.49	1051.06	597.5	2.12	2.65	1.00	8.5	9.5	2.30	2.32	20.1
6	221H-PT3-N-2CC	2871.57	3082.55	3110.20	1783.5	2.16	2.64	1.00	7.3	8.3	2.32	2.34	18.0
7	221H-PT3-N-1CC	1121.66	1205.50	1213.60	698.5	2.18	2.65	1.00	7.5	8.2	2.34	2.36	17.8

* Over Core

Absorption after immersion [%]	% = [(B-A)/A] X 100
Absorption after immersion and boiling [g]	% = [(C-A)/A] X 100
Bulk density, dry	g_1 = [A/(C-D)] X ρ
Bulk density after immersion	BDAI = [B/(C-D)] X ρ
Bulk density after immersion and boiling	BDAIB = [C/(C-D)] X ρ
Apparent Density	g_2 = [A/(A-D)] X ρ
Volume of permeable pore space (voids) [%]	% = (g_2 - g_1)/g_2 x 100

Comments: N/A

1-12-17

ASR 18-202 (4/13)

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Savannah River Site
Compressive Strength of Drilled Cores

ASTM C 39- (14) ASTM C 42-(13) ASTM C 617-(12)

Report No.: 2016-CAEX-0008 Project No.: N/A Work Package No.: 1525456 Design Cat.: SC

QCIR No.: N/A Date & Time Core Taken: 12-21-16 @ N/A Concrete Supplier: N/A Placement Date: 1952

Placement Location: 221H- Section 3, Personnel Tunnel North Wall Mix Design: N/A Design Strength: 2500 psi @ N/A Days

Lab. Number	Days Aged	Date Tested	Length Before Capping, in.	Length After Capping, in.	Average Diameter, in.	Area, sq.in.	Total Load, lbs.	Length to Diameter Ratio	Correction Factor	Unit Load, psi	Corrected psi	Technician Init./Level
160101	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
N-5-A	7	12-29-16	11.09	11.39	5.67	25.25	61113	2.01	1.00	2420	2420	GS III
N-5-B	7	12-29-16	11.01	11.35	5.67	25.25	55520	2.00	1.00	2200	2200	GS III

N/A

Direction of Application of the Load on the Specimen with Respect to the Horizontal Plane of the Concrete Placed: N/A

Nominal Maximum Size of Aggregate: N/A Method of Test: N/A

M&TE: 1) CA-002; 2) TM-5

Cal. Due Date: 1) 9-23-17; 2) 1-12-17

Test Results: ☐ Conforming ☐ Nonconforming ☒ *X N/A

NCR No.: N/A

Procedure: C-QCP-002 Rev.: 0 PCN(s): N/A

Remarks: *For Engineering Evaluation. Density of Cores follows:
221H-PT3-N-5-A = 140 pcf; 221H-PT3-N-5-B = 141 pcf;
N/A

Spec.: C-ESR-H-00044 Rev.: 0 DCF(s): N/A

Dwg(s): N/A Rev.: N/A DCF(s): N/A

Technician (Print/Sign): Glenn C. Spencer/ [signature] Level: III Date: 12-29-16

Reviewer (Print/Sign): Charles A. Bookhamer/ Charles A. Bookhamer Level: III Date: 1-11-17

THIS REPORT SHALL NOT BE REPRODUCED, EXCEPT IN FULL, WITHOUT THE WRITTEN APPROVAL OF THE LABORATORY.

1-12-17

1-12-17

ASR 18-203 (04/13)

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Savannah River Site

Summary Report of Testing Activities

☐ Report ☒ Cover Sheet Page 1 of 3

Approvals (If required)	Work Package No.: 1525456
Senior Civil Technician (Level III): Charles A. Bookhamer	QCIR No.: N/A Project No.: N/A
Civil Testing & Inspection Superintendent: W. Pope, Jr.	Design Category: ~~GS~~ SC CAB 1-11-17 Report No.: 2016-CAEX-0007 Date: 12-20-16
Lab. No.: 160100	Test Method: See attached pages
Discipline: Civil	Description: Concrete
Location: 221H Personnel Tunnel 3 North Wall	Reported to: J. Carter, 8-1727

Summary: This report presents the data required by the H-Area CAEX Tunnel Concrete Core Sampling Plan, C-ESR-H-00044, Revision 0. Page 2 contains a spreadsheet for data and results provided by the calculations of ASTM C642-13 covering the determination of density, percent absorption, and percent voids in hardened concrete.
Line 1 on page 2 references Sample ID 221H-PT3-N-6OC for this report.
See page 3 for the results of "Compressive Strength of Drilled Cores". Also note, the densities of the core segments are provided in the page 3 Remarks Section.
All information in this report is from over core and core segments from sample location ~~221H-PT3-S-6.~~ 221H-PT3-N-6. 8-22-17 W.P.

N/A

M&TE: See attached pages	Cal. Due Date: See attached pages	Procedure: C-QCP-002
NCR No.: N/A		Rev.: 0
Test Results: ☐ Conforming ☐ Nonconforming ☒* N/A		PCN(s): N/A
Remarks: * For engineering evaluation N/A		Spec.: C-~~ERS~~ ESR-H-00044 BJ2 1-12-17
		Rev.: 0
		DCF(s): N/A

Technician (Print/Sign): Charles A. Bookhamer/ *Charles A. Bookhamer*		Level: III	Date: 1-11-17
Reviewer (Print/Sign): Charles Z. Moore/ *C Z Moore* CZM 1-12-17		Level: II KM III	Date: 1-11-17 8-22-17

THIS REPORT SHALL NOT BE REPRODUCED, EXCEPT IN FULL, WITHOUT THE WRITTEN APPROVAL OF THE LABORATORY.

8-22-17 1-12-17

ASR 18-250 (04/13)

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Savannah River Site

Summary Report of Testing Activities (Continuation Sheet)

Report Title: 221H Personnel Tunnel 3 North Wall **Report No.:** 2016-CAEX-0007

Item #	Summary

Density, Absorption, and Voids in Hardened Concrete

A = mass of oven-dried sample in air [g]
B = mass of surface-dry sample in air after immersion [g]
C = mass of surface-dry sample in air after immersion and boiling [g]
D = apparent mass of sample in water after immersion and boiling [g]
g_1 = bulk density, dry, Mg/m^3, or g/cm^3
g_2 = aparent bulk density, Mg/m^3, or g/cm^3
ρ = density of water = 1 Mg/m^3 = 1 g/cm^3

AAI = Absorption after immersion [%]
AAIB = Absorption after immersion and boiling [g]
g_1 = Bulk density, dry
BDAI = Bulk density after immersion
BDAIB = Bulk density after immersion and boiling
g_2 = Apparent Density
VPP = Volume of permeable pore speac (voids) [%]

Line	Sample ID	A [g]	B [g]	C [g]	D [g]	g_1 [g/cm^3]	g_2 [g/cm^3]	ρ [g/cm^3]	AAI [%]	AAIB [%]	BDAI [g/cm^3]	BDAIB [g/cm^3]	VPP [%]
1	*221H-PT3-N-6OC	1143.25	1243.83	1251.99	712.6	2.12	2.65	1.00	8.8	9.5	2.31	2.32	20.2
2	*221H-PT3-N- 5OC	1660.96	1797.27	1811.47	1034.2	2.14	2.65	1.00	8.2	9.1	2.31	2.33	19.4
3	221H-PT3-N-5BB	1676.66	1807.66	1822.62	1042.7	2.15	2.64	1.00	7.8	8.7	2.32	2.34	18.7
4	221H-PT3-N-4CC	2127.10	2295.52	2314.88	1324.2	2.15	2.65	1.00	7.9	8.8	2.32	2.34	19.0
5	*221H-PT3-N-4OC	959.79	1041.49	1051.06	597.5	2.12	2.65	1.00	8.5	9.5	2.30	2.32	20.1
6	221H-PT3-N-2CC	2871.57	3082.55	3110.20	1783.5	2.16	2.64	1.00	7.3	8.3	2.32	2.34	18.0
7	221H-PT3-N-1CC	1121.66	1205.50	1213.60	698.5	2.18	2.65	1.00	7.5	8.2	2.34	2.36	17.8

* Over Core

Absorption after immersion [%]	% = [(B-A)/A] X 100
Absorption after immersion and boiling [g]	% = [(C-A)/A] X 100
Bulk density, dry	g_1 = [A/(C-D)] X ρ
Bulk density after immersion	BDAI = [B/(C-D)] X ρ
Bulk density after immersion and boiling	BDAIB = [C/(C-D)] X ρ
Apparent Density	g_2 = [A/(A-D)] X ρ
Volume of permeable pore space (voids) [%]	% = (g_2 - g_1)/g_2 x 100

Comments: N/A

1-12-17

ASR 18-202 (4/13)

URS
Savannah River Site
Compressive Strength of Drilled Cores

ASTM C 39- (14) ASTM C 42-(13) ASTM C 617-(12)

Report No.: 2016-CAEX-0007 Project No.: N/A Work Package No.: 1525456 Design Cat.: SC

QCIR No.: N/A Date & Time Core Taken: 12-20-16 @ N/A Concrete Supplier: N/A Placement Date: 1952

Placement Location: 221H- Section 3, Personnel Tunnel North Wall Mix Design: N/A Design Strength: 2500 psi @ N/A Days

Lab. Number	Days Aged	Date Tested	Length Before Capping, in.	Length After Capping, in.	Average Diameter, in.	Area, sq.in.	Total Load, lbs.	Length to Diameter Ratio	Correction Factor	Unit Load, psi	Corrected psi	Technician Init./Level
160100	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
N-6-A	7	12-29-16	7.10	7.35	3.73	10.93	23009	1.97	1.00	2110	2110	GS III
N-6-B	7	12-29-16	7.00	7.22	3.73	10.93	23437	1.94	1.00	2140	2140	GS III
N-6-C	7	12-29-16	7.05	7.21	3.73	10.93	24358	1.93	1.00	2230	2230	GS III
					N	A						

Direction of Application of the Load on the Specimen with Respect to the Horizontal Plane of the Concrete Placed: N/A

Nominal Maximum Size of Aggregate: N/A Method of Test: N/A

M&TE: 1) CA-002; 2) TM-5

Cal. Due Date: 1) 9-23-17; 2) 1-12-17

Test Results: ☐ Conforming ☐ Nonconforming ☒ *X N/A

NCR No.: N/A

Remarks: *For Engineering Evaluation. Density of Cores follows:
221H-PT3-N-6-A = 142 pcf; 221H-PT3-N-6-B = 142 pcf; 221H-PT3-N-6-C = 141 pcf;
N/A

Procedure: C-QCP-002 Rev.: 0 PCN(s): N/A

Spec.: C-ESR-H-00044 Rev.: 0 DCF(s): N/A

Dwg(s): N/A Rev.: N/A DCF(s): N/A

Technician (Print/Sign): Glenn C. Spencer/ Glenn C. Spencer Level: III Date: 12-29-16

Reviewer (Print/Sign): Charles A. Bookhamer/ Charles A. Bookhamer Level: III Date: 1-11-17

THIS REPORT SHALL NOT BE REPRODUCED, EXCEPT IN FULL, WITHOUT THE WRITTEN APPROVAL OF THE LABORATORY.

1-12-17

URS
Savannah River Site
Summary Report of Testing Activities

☐ Report ☒ Cover Sheet

Approvals (If required)	Work Package No.: 1525456
Senior Civil Technician (Level III): Glenn Specner	QCIR No.: N/A Project No.: N/A
Civil Testing & Inspection Superintendent: W. Pope, Jr.	Design Category: SC Report No.: 2017-CAEX-0002 Date: 3-1-17
Lab. No.: 170011,170012,170013,170014	Test Method: See attached pages
Discipline: Civil	Description: Concrete
Location: 221H Personnel Tunnel 3 North Wall	Reported to: J. Carter, 8-1727

Summary: This report presents the data required by the H-Area CAEX Tunnel Concrete Core Sampling Plan, C-ESR-H-00044, Revision 0. Page 6 contains a spreadsheet for data and results provided by the calculations of ASTM C642-13 covering the determination of density, percent absorption, and percent voids in hardened concrete. Line 7 on page 6 references . See pages 2 ,3,4 and 5 for the results of "Compressive Strength of Drilled Cores". Also note, the densities of the core segments are provided in the pages 2 ,3,4 and 5 Remarks Section.

All INFORMATION IN THIS REPORT IS FROM CORE SEGMENTS FROM SAMPLE LOCATIONS 221H-PT3-N-6A, 221H-PT3-N-2A, 221H-PT3-N-2B AND 221H-PT3-N-2C. 8-22-17 W.P.

N
A

M&TE: See attached pages / Cal. Due Date: See attached pages	Procedure: C-QCP-002
NCR No.: N/A	Rev.: 0
Test Results: ☐ Conforming ☐ Nonconforming ☒* N/A	PCN(s): N/A
Remarks: * For engineering evaluation N/A	Spec.: C-ESR-H-00044
	Rev.: 0
	DCF(s): N/A

Technician (Print/Sign): Glenn Spencer/ [signature] Level: III Date: 3/20/17

Reviewer (Print/Sign): Kevin Miller KEVIN MILLER Level: III Date: 3/27/17
KM 8-22-17

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8/22/17 4-3-17

ASR 18-202 (4/13)

URS
Savannah River Site

Compressive Strength of Drilled Cores

ASTM C 39- (14) ASTM C 42-(13) ASTM C 617-(12)

Report No.: 2017-CAEX-0002 Project No.: N/A Work Package No.: 1525456 Design Cat.: ~~GS~~ SC 3-29-17

QCIR No.: N/A Date & Time Core Taken: 3-1-17 @ N/A Concrete Supplier: N/A Placement Date: 1952

Placement Location: 221H- Section 6A, Personnel Tunnel North Wall Mix Design: N/A Design Strength: 2500 psi @ N/A Days

Lab. Number	Days Aged	Date Tested	Length Before Capping, in.	Length After Capping, in.	Average Diameter, in.	Area, sq.in.	Total Load, lbs.	Length to Diameter Ratio	Correction Factor	Unit Load, psi	Corrected psi	Technician Init./Level
170011	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
6A-A	6	3-8-17	7.42	7.62	3.72	10.87	29280	2.05	1.00	2690	N/A	GS III
6A-B	6	3-8-17	7.43	7.62	3.71	10.81	28209	2.05	1.00	2610	N/A	GS III
6A-C	6	3-8-17	7.40	7.57	3.71	10.81	31745	2.04	1.00	2940	N/A	GS III
						NA						

Direction of Application of the Load on the Specimen with Respect to the Horizontal Plane of the Concrete Placed: N/A

Nominal Maximum Size of Aggregate: N/A Method of Test: N/A

M&TE: 1) CA-002; 2) TM-5	Cal. Due Date: 1) 9-23-17; 2) 1-11-18
Test Results: ☐ Conforming ☐ Nonconforming ☒ *X N/A	NCR No.: N/A
Remarks: *For Engineering Evaluation. Density of Cores follows:	Procedure: C-QCP-002 Rev.: 0 PCN(s): N/A
221H-PT3-N-6A-A = 145 pcf; 221H-PT3-N-6A-B = 145 pcf;	Spec.: C-ESR-H-00044 Rev.: 0 DCF(s): N/A
221H-PT3-N-6A-C = 143 pcf;	Dwg(s): N/A Rev.: N/A DCF(s): N/A

Technician (Print/Sign): Glenn Spencer [signature] Level: III Date: 3-8-17

Reviewer (Print/Sign): Kevin Miller/ KEVIN MILLER Re-Review KEVIN MILLER 3-29-17 Level: III Date: 3/27/17

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ASR 18-202 (4/13)

URS
Savannah River Site
Compressive Strength of Drilled Cores

ASTM C 39- (14) ASTM C 42-(13) ASTM C 617-(12)

Report No.: 2017-CAEX-0002 Project No.: N/A Work Package No.: 1525456 Design Cat.: ~~GS~~ GSC 3-24-17

QCIR No.: N/A Date & Time Core Taken: 3-1-17 @ N/A Concrete Supplier: N/A Placement Date: 1952

Placement Location: 221H- Section 2A, Personnel Tunnel North Wall Mix Design: N/A Design Strength: 2500 psi @ N/A Days

Lab. Number	Days Aged	Date Tested	Length Before Capping, in.	Length After Capping, in.	Average Diameter, in.	Area, sq.in.	Total Load, lbs.	Length to Diameter Ratio	Correction Factor	Unit Load, psi	Corrected psi	Technician Init./Level
170012	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2A-A	6	3-8-17	7.38	7.55	3.73	10.93	20778	2.02	1.00	1900	N/A	GS III
2A-B	6	3-8-17	7.47	7.64	3.73	10.93	22723	2.05	1.00	2080	N/A	GS III
2A-C	6	3-8-17	7.45	7.59	3.72	10.87	23844	2.04	1.00	2190	N/A	GS III
						NA						

Direction of Application of the Load on the Specimen with Respect to the Horizontal Plane of the Concrete Placed: N/A

Nominal Maximum Size of Aggregate: N/A Method of Test: N/A

M&TE: 1) CA-002; 2) TM-5

Cal. Due Date: 1) 9-23-17; 2) 1-11-18

Test Results: ☐ Conforming ☐ Nonconforming ☒ *X N/A

NCR No.: N/A

Procedure: C-QCP-002 Rev.: 0 PCN(s): N/A

Remarks: *For Engineering Evaluation. Density of Cores follows:
221H-PT3-N-2A-A = 142 pcf; 221H-PT3-N-2A-B = 142 pcf;
221H-PT3-N-2A-C = 143 pcf;

Spec.: C-ESR-H-00044 Rev.: 0 DCF(s): N/A

Dwg(s): N/A Rev.: N/A DCF(s): N/A

Technician (Print/Sign): Glenn Spencer [signature] Level: III Date: 3-8-17

Reviewer (Print/Sign): Kevin Miller/ KEVIN MILLER Re-Review KEVIN MILLER 3-29-17 Level: III Date: 3/27/17

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ASR 18-202 (4/13)

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Savannah River Site

Compressive Strength of Drilled Cores

ASTM C 39- (14) ASTM C 42-(13) ASTM C 617-(12)

Report No.: 2017-CAEX-0002 Project No.: N/A Work Package No.: 1525456 Design Cat.: ~~GS~~ SC 3-24-17

QCIR No.: N/A Date & Time Core Taken: 3-1-17 @ N/A Concrete Supplier: N/A Placement Date: 1952

Placement Location: 221H- Section 2B, Personnel Tunnel North Wall Mix Design: N/A Design Strength: 2500 psi @ N/A Days

Lab. Number	Days Aged	Date Tested	Length Before Capping, in.	Length After Capping, in.	Average Diameter, in.	Area, sq.in.	Total Load, lbs.	Length to Diameter Ratio	Correction Factor	Unit Load, psi	Corrected psi	Technician Init./Level
170013	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2B-A	6	3-8-17	7.31	7.47	3.73	10.93	24248	2.00	1.00	2220	N/A	GS III
2B-B	6	3-8-17	7.47	7.62	3.73	10.93	20684	2.04	1.00	1890	N/A	GS III
2B-C	6	3-8-17	7.33	7.52	3.73	10.93	21430	2.04	1.00	1960	N/A	GS III
						NA						

Direction of Application of the Load on the Specimen with Respect to the Horizontal Plane of the Concrete Placed: N/A

Nominal Maximum Size of Aggregate: N/A Method of Test: N/A

M&TE: 1) CA-002; 2) TM-5

Cal. Due Date: 1) 9-23-17; 2) 1-11-18

Test Results: ☐ Conforming ☐ Nonconforming ☒ *X N/A

NCR No.: N/A

Procedure: C-QCP-002 Rev.: 0 PCN(s): N/A

Remarks: *For Engineering Evaluation. Density of Cores follows:
221H-PT3-N-2B-A = 141 pcf; 221H-PT3-N-2B-B = 140 pcf;
221H-PT3-N-2B-C = 139 pcf;

Spec.: C-ESR-H-00044 Rev.: 0 DCF(s): N/A

Dwg(s): N/A Rev.: N/A DCF(s): N/A

Technician (Print/Sign): Glenn Spencer [signature] Level: III Date: 3-8-17

Reviewer (Print/Sign): Kevin Miller/ KEVIN MILLER Re-Review KEVIN MILLER 3-29-17 Level: III Date: 3/27/17

ASR 18-202 (4/13)

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Savannah River Site

Compressive Strength of Drilled Cores

ASTM C 39- (14) ASTM C 42-(13) ASTM C 617-(12)

Report No.: 2017-CAEX-0002 Project No.: N/A Work Package No.: 1525456 Design Cat.: ~~GS~~ SC 3-24-17

QCIR No.: N/A Date & Time Core Taken: 3-1-17 @ N/A Concrete Supplier: N/A Placement Date: 1952

Placement Location: 221H- Section 2C, Personnel Tunnel North Wall Mix Design: N/A Design Strength: 2500 psi @ N/A Days

Lab. Number	Days Aged	Date Tested	Length Before Capping, in.	Length After Capping, in.	Average Diameter, in.	Area, sq.in.	Total Load, lbs.	Length to Diameter Ratio	Correction Factor	Unit Load, psi	Corrected psi	Technician Init./Level
170014	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2C-A	6	3-8-17	7.40	7.59	3.73	10.93	19372	2.03	1.00	1770	N/A	GS III
2C-B	6	3-8-17	7.51	7.63	3.73	10.93	22507	2.05	1.00	2060	N/A	GS III
						N/A						

Direction of Application of the Load on the Specimen with Respect to the Horizontal Plane of the Concrete Placed: N/A

Nominal Maximum Size of Aggregate: N/A Method of Test: N/A

M&TE: 1) CA-002; 2) TM-5

Cal. Due Date: 1) 9-23-17; 2) 1-11-18

Test Results: ☐ Conforming ☐ Nonconforming ☒ *X N/A

NCR No.: N/A

Procedure: C-QCP-002 Rev.: 0 PCN(s): N/A

Remarks: *For Engineering Evaluation. Density of Cores follows:
221H-PT3-N-2C-A = 141 pcf; 221H-PT3-N-2C-B = 142 pcf;

Spec.: C-ESR-H-00044 Rev.: 0 DCF(s): N/A

Dwg(s): N/A Rev.: N/A DCF(s): N/A

Technician (Print/Sign): Glenn Spencer [signature] Level: III Date: 3-8-17

Reviewer (Print/Sign): Kevin Miller/ KEVIN MILLER Re-Review KEVIN MILLER 3-29-17 Level: III Date: 3/27/17

ASR 18-250 (4/13)

URS

Savannah River Site

Summary Report of Testing Activities (Continuation Sheet)

Report Title: 221 H Personnel Tunnel 3 North Wall **Report No.:** 2017-CAEX-0002

Item #	Summary

Density, Absorption, and Voids in Hardened Concrete

A = mass of oven-dried sample in air [g]
B = mass of surface-dry sample in air after immersion [g]
C = mass of surface-dry sample in air after immersion and boiling [g]
D = apparent mass of sample in water after immersion and boiling [g]
g_1 = bulk density, dry, Mg/m^3, or g/cm^3
g_2 = aparent bulk density, Mg/m^3, or g/cm^3
p = density of water = 1 Mg/m^3 = 1 g/cm^3

AAI = Absorption after immersion [%]
AAIB = Absorption after immersion and boiling [g]
g_1 = Bulk density, dry
BDAI = Bulk density after immersion
BDAIB = Bulk density after immersion and boiling
g_2 = Apparent Density
VPP = Volume of permeable pore speac (voids) [%]

		A	B	C	D	g_1	g_2	ρ	AAI	AAIB	BDAI	BDAIB	VPP
Line	Sample ID	[g]	[g]	[g]	[g]	[g/cm^3]	[g/cm^3]	[g/cm^3]	[%]	[%]	[g/cm^3]	[g/cm^3]	[%]
1	221H-PT3-N-6A	1079.20	1156.80	1172.70	671.2	2.15	2.65	1.00	7.2	8.7	2.31	2.34	18.6
2	221H-PT3-N-2C	986.60	1060.20	1067.60	613.6	2.17	2.65	1.00	7.5	8.2	2.34	2.35	17.8

* Undersized Sample

Absorption after immersion [%]	% = [(B-A)/A] X 100
Absorption after immersion and boiling [g]	% = [(C-A)/A] X 100
Bulk density, dry	g_1 = [A/(C-D)] X p
Bulk density after immersion	BDAI = [B/(C-D)] X p
Bulk density after immersion and boiling	BDAIB = [C/(C-D)] X p
Apparent Density	g_2 = [A/(A-D)] X p
Volume of permeable pore space (voids) [%]	% = (g_2 - g_1)/g_2 x 100

Comments: N/A

9-14-17

URS
Savannah River Site

Summary Report of Testing Activities

☐ Report ☒ Cover Sheet

Approvals (If required)	Work Package No.: 1525456
Senior Civil Technician (Level III): Glenn Specner	QCIR No.: N/A Project No.: N/A
Civil Testing & Inspection Superintendent: W. Pope, Jr.	Design Category: SC Report No.: 2017-CAEX-0001 Date: 2-28-17
Lab. No.: 170008-170009	Test Method: See attached pages
Discipline: Civil	Description: Concrete
Location: 221H Personnel Tunnel 3 North Wall	Reported to: J. Carter, 8-1727

Summary: This report presents the data required by the H-Area CAEX Tunnel Concrete Core Sampling Plan, C-ESR-H-00044, Revision 0. Page 4 contains a spreadsheet for data and results provided by the calculations of ASTM C642-13 covering the determination of density, percent absorption, and percent voids in hardened concrete. Line 7 on page 4 references . See page 2 and 3 for the results of "Compressive Strength of Drilled Cores". Also note, the densities of the core segments are provided in the page 2 and 3 Remarks Section.

All INFORMATION IN THIS REPORT IS FROM CORE SEGMENTS FROM SAMPLE LOCATIONS 221H-PT3-N-10B AND 221H-PT3-N-10C. 8-22-17 W.P.

N
A

M&TE: See attached pages	Cal. Due Date: See attached pages	Procedure: C-QCP-002
NCR No.: N/A		Rev.: 0
Test Results: ☐ Conforming ☐ Nonconforming ☒* N/A		PCN(s): N/A
Remarks: * For engineering evaluation N/A		Spec.: C-ESR-H-00044 Rev.: 0 DCF(s): N/A

Technician (Print/Sign): Glenn Spencer/ [signature] Level: III Date: 3/20/17

Reviewer (Print/Sign): Kevin Miller KEVIN MILLER Level: III Date: 3/27/17

KM 8-22-17

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[signature] 4-3-17

ASR 18-202 (4/13)

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Savannah River Site

Compressive Strength of Drilled Cores

ASTM C 39- (14) ASTM C 42-(13) ASTM C 617-(12)

Report No.: 2017-CAEX-0001 Project No.: N/A Work Package No.: 1525456 Design Cat.: ~~GS~~ SC 3-29-17

QCIR No.: N/A Date & Time Core Taken: 2-28-17 @ N/A Concrete Supplier: N/A Placement Date: 1952

Placement Location: 221H- Section 6c, Personnel Tunnel North Wall Mix Design: N/A Design Strength: 2500 psi @ N/A Days

Lab. Number	Days Aged	Date Tested	Length Before Capping, in.	Length After Capping, in.	Average Diameter, in.	Area, sq.in.	Total Load, lbs.	Length to Diameter Ratio	Correction Factor	Unit Load, psi	Corrected psi	Technician Init./Level
170009	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
6C-A	6	3-6-17	7.37	7.56	3.70	10.75	21794	2.04	1.00	2030	N/A	GS III
6C-B	6	3-6-17	7.33	7.52	3.71	10.81	23583	2.03	1.00	2180	N/A	GS III
6C-C	7	3-7-17	7.53	7.71	3.71	10.81	22997	2.08	1.00	2130	N/A	GS III
						NA						

Direction of Application of the Load on the Specimen with Respect to the Horizontal Plane of the Concrete Placed: N/A

Nominal Maximum Size of Aggregate: N/A Method of Test: N/A

M&TE: 1) CA-002; 2) TM-5

Cal. Due Date: 1) 9-23-17; 2) 1-11-18

Test Results: ☐ Conforming ☐ Nonconforming *X N/A

NCR No.: N/A

Procedure: C-QCP-002 Rev.: 0 PCN(s): N/A

Remarks: *For Engineering Evaluation. Density of Cores follows:
221H-PT3-N-6C-A = 140 pcf; 221H-PT3-N-6C-B = 142 pcf; 221H-PT3-N-6C-C =
221H-PT3-N-6C-C =142pcf;

Spec.: C-ESR-H-00044 Rev.: 0 DCF(s): N/A

Dwg(s): N/A Rev.: N/A DCF(s): N/A

Technician (Print/Sign): Glenn Spencer Level: III Date: 3-7-17 3-29-17

Reviewer (Print/Sign): Kevin Miller/ KEVIN MILLER Re-Review KEVIN MILLER 3-29-17 Level: III Date: 3/27/17

ASR 18-202 (4/13)

URS

Savannah River Site

Compressive Strength of Drilled Cores

ASTM C 39- (14) ASTM C 42-(13) ASTM C 617-(12)

Report No.: 2017-CAEX-0001 Project No.: N/A Work Package No.: 1525456 Design Cat.: ~~GS~~ SC 3-29-17

QCIR No.: N/A Date & Time Core Taken: 2-28-17 @ N/A Concrete Supplier: N/A Placement Date: 1952

Placement Location: 221H- Section 6B, Personnel Tunnel North Wall Mix Design: N/A Design Strength: 2500 psi @ N/A Days

Lab. Number	Days Aged	Date Tested	Length Before Capping, in.	Length After Capping, in.	Average Diameter, in.	Area, sq.in.	Total Load, lbs.	Length to Diameter Ratio	Correction Factor	Unit Load, psi	Corrected psi	Technician Init./Level
170008	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
6B-A	6	3-6-17	7.38	7.58	3.71	10.81	27031	2.04	1.00	2500	N/A	GS III
6B-B	6	3/6/17	7.35	7.52	3.68	10.64	27151	2.04	1.00	2550	N/A	GS III
						N/A						

Direction of Application of the Load on the Specimen with Respect to the Horizontal Plane of the Concrete Placed: N/A

Nominal Maximum Size of Aggregate: N/A Method of Test: N/A

M&TE: 1) CA-002; 2) TM-5	Cal. Due Date: 1) 9-23-17; 2) 1-11-18
Test Results: ☐ Conforming ☐ Nonconforming ☒ *X N/A	NCR No.: N/A
Remarks: *For Engineering Evaluation. Density of Cores follows:	Procedure: C-QCP-002 Rev.: 0 PCN(s): N/A
221H-PT3-N-6B-A = 143 pcf; 221H-PT3-N-6B-B = 143 pcf;	Spec.: C-ESR-H-00044 Rev.: 0 DCF(s): N/A
	Dwg(s): N/A Rev.: N/A DCF(s): N/A

Technician (Print/Sign): Glenn Spencer [signature] Level: III Date: 3-6-17

Reviewer (Print/Sign): Kevin Miller/ KEVIN MILLER Re-Review KEVIN MILLER 3-29-17 Level: III Date: 3/27/17

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ASR 18-250 (4/13)

URS
Savannah River Site

Summary Report of Testing Activities (Continuation Sheet)

Report Title: 221 H Personnel Tunnel 3 North Wall **Report No.:** 2017-CAEX-0001

Item #	Summary

Density, Absorption, and Voids in Hardened Concrete

A = mass of oven-dried sample in air [g]
B = mass of surface-dry sample in air after immersion [g]
C = mass of surface-dry sample in air after immersion and boiling [g]
D = apparent mass of sample in water after immersion and boiling [g]
g_1 = bulk density, dry, Mg/m^3, or g/cm^3
g_2 = aparent bulk density, Mg/m^3, or g/cm^3
ρ = density of water = 1 Mg/m^3 = 1 g/cm^3

AAI = Absorption after immersion [%]
AAIB = Absorption after immersion and boiling [g]
g_1 = Bulk density, dry
BDAI = Bulk density after immersion
BDAIB = Bulk density after immersion and boiling
g_2 = Apparent Density
VPP = Volume of permeable pore speac (voids) [%]

Line	Sample ID	A [g]	B [g]	C [g]	D [g]	g_1 [g/cm^3]	g_2 [g/cm^3]	ρ [g/cm^3]	AAI [%]	AAIB [%]	BDAI [g/cm^3]	BDAIB [g/cm^3]	VPP [%]
1	221H-PT3-N-6C	1081.80	1159.70	1164.40	673.5	2.20	2.65	1.00	7.2	7.6	2.36	2.37	16.8
2	221H-PT3-N-6B-C	940.10	1012.80	1018.20	585.5	2.17	2.65	1.00	7.7	8.3	2.34	2.35	18.0
3	221H-PT3-N-6B	1166.10	1251.20	1264.50	725.6	2.16	2.65	1.00	7.3	8.4	2.32	2.35	18.3

* Undersized Sample

Absorption after immersion [%]	% = [(B-A)/A] X 100
Absorption after immersion and boiling [g]	% = [(C-A)/A] X 100
Bulk density, dry	g_1 = [A/(C-D)] X ρ
Bulk density after immersion	BDAi = [B/(C-D)] X ρ
Bulk density after immersion and boiling	BDAIB = [C/(C-D)] X ρ
Apparent Density	g_2 = [A/(A-D)] X ρ
Volume of permeable pore space (voids) [%]	% = (g_2 - g_1)/g_2 x 100

Comments: N/A

9-14-17

Appendix F. Non-Radiologically Contaminated South Wall Concrete Cores - UPV Data Sheets

1/13/17 H area concrete

Rebar embedded at position #3

PT3-S-4-CC	1	2	3	4	5	6	7	
Transmission Time	22.2µs	21.4	22.1					
Distance	0.3098	0.310	0.3103					
Pulse Velocity	13964	14486	14027					
Compressive Strength								
E-Modulus								
Physical Measurement	3.717	3.720	3.724					
PT3-N-2-B	1	2	3	4	5	6	7	
Transmission Time	38.9	37.9	39.3	39.8	39.6	40.9	37.5	
Distance	0.473	0.473	0.474	0.4745	0.473	0.473	0.473	
Pulse Velocity	12159	12480	12082	11935	11944	11795	12613	
Compressive Strength								
E-Modulus								
Physical Measurement	5.675	5.680	5.689	5.694	5.680	5.670	5.676	
	~~1~~ 8	~~2~~ 9	~~3~~ 10	4	5	6	7	
Transmission Time	38.3	41.4	43.5					
Distance	0.473	0.473	0.472					
Pulse Velocity	12350	11425	10851					11964 Ave
Compressive Strength								
E-Modulus								
Physical Measurement	5.680	5.678	5.672					
PT3-N-1-13	1	2	3	4	5	6	7	
Transmission Time	25.7	22.5	22.5	22.5	22.9	23.8		
Distance	0.311	0.311	0.311	0.311	0.311	0.311		
Pulse Velocity	12101	13822	13822	13822	13463	13067		13349
Compressive Strength								
E-Modulus								
Physical Measurement	3.726	3.730	3.730	3.730	3.730	3.732		
	1	2	3	4	5	6	7	
Transmission Time								
Distance								
Pulse Velocity								
Compressive Strength								
E-Modulus								
Physical Measurement								
	1	2	3	4	5	6	7	
Transmission Time								
Distance								
Pulse Velocity								
Compressive Strength								
E-Modulus								
Physical Measurement								

24.7
23.7
13122

C-Core

1-724-512-0330
JoE-Forelley

Pr - Personnel Tunnel #3 221-H South Wall

PT3-S-2-D	1	2	3	4	5	6	7	
Transmission Time	20.8	19.3	20.5	20.2	19.2			
Distance	.310	.310	.310	.310	.310			
Pulse Velocity	14904	16062	15271	15347	16146	N	N	15546
Compressive Strength						A	A	3280
E-Modulus								
Physical Measurement	31/3.720	31/3.720	3.727 .31	3.728 .31	3.728 .31			21 %
PT3-S-6-D	1	2	3	4	5	6	7	23.25 %
Transmission Time	19.7	19.9	19.5	19.3	19.6			
Distance	.31	.311	.311	.311	.310			
Pulse Velocity	15736	15578	16114	16114	15816	N	N	15871
Compressive Strength						A	A	4070
E-Modulus								
Physical Measurement	3.724	3.750	3.750	3.750	3.725			25 %
PT3-S-1-D	1	2	3	4	5	6	7	28.4 %
Transmission Time	19.2	20.5	21	21	20.6	20.2	20.1	15297
Distance	.311	.311	.311	.311	.312	.312	.312	3243
Pulse Velocity	16198	15171	14810	14810	15171	15396	15522	21.2 %
Compressive Strength								23.57 %
E-Modulus								
Physical Measurement	3.734	3.732	3.736	3.737	3.740	3.740	3.740	
PT3-S-5-D	1	2	3	4	5	6	7	
Transmission Time	21.7	18.7	18.8	20.4	21.1			15448
Distance	.310	.311	.310	.310	.310	N	N	3457
Pulse Velocity	14286	16578	16489	15196	14692	A	A	22.2 %
Compressive Strength								23.5 %
E-Modulus								
Physical Measurement	3.723	3.727	3.723	3.723	3.724			
PT3-S-4-D	1	2	3	4	5	6	7	
Transmission Time	21.2	22	21.6	20.7	19.9			
Distance	.31	.310	.310	.310	.310			
Pulse Velocity	14623	14091	14352	14976	15578	N	N	14724
Compressive Strength						A	A	3543
E-Modulus								24 %
Physical Measurement	3.715	3.715	3.717	3.718	3.720			26 %
PT3-S-3D	1	2	3	4	5	6	7	
Transmission Time	19.5	20.1	20.2	19.8	19.8			15611
Distance	.31	.31	.310	.310	.311			3917
Pulse Velocity	15897	15423	15423	15657	15657			25 %
Compressive Strength								27 %
E-Modulus								
Physical Measurement	3.720	3.720	3.722	3.723	3.729			

In Distance

A-D Ave 23.06 %
Ave B-D = 25.25 %

24.7
23.7
13122

LC-Core

1-724-512-0330
JoE-Forcelley

Pr - Personnel Tunnel #3 221-H
South Wall

PT3-S-2-D	1	2	3	4	5	6	7
Transmission Time	20.8	19.3	20.3	20.2	19.2		
Distance	.310	.310	.310	.310	.310		
Pulse Velocity	14904	16062	15271	15347	16146	N	N
Compressive Strength						A	A
E-Modulus							
Physical Measurement	31/3.720	31/3.720	3.727 .311	3.728 .31	3.728 .311		

15546
3280
21 %
23.25 %

PT3-S-6-D	1	2	3	4	5	6	7
Transmission Time	19.7	19.9	19.3	19.3	19.6		
Distance	.31	.3.11	.3.11	.311	.310		
Pulse Velocity	15736	15578	16114	16114	15816	N	N
Compressive Strength						A	A
E-Modulus							
Physical Measurement	3.724	.3.730	3.730	3.730	3.725		

15871
4070
25%
28.4%

PT3-S-1-D	1	2	3	4	5	6	7
Transmission Time	19.2	20.5	21	21	20.[illegible]	20.2	20.1
Distance	.311	.311	.311	.311	.312	.312	.312
Pulse Velocity	16198	15171	14810	14810	15171	15396	15522
Compressive Strength							
E-Modulus							
Physical Measurement	3.734	3.732	3.736	3.737	3.740	3.740	3.740

15297
3243
21.2%
23.57%

PT3-S-5-D	1	2	3	4	5	6	7
Transmission Time	21.7	18.7	18.8	20.4	21.1		
Distance	.310	.311	.310	.310	.310	N	N
Pulse Velocity	14286	16578	16489	15196	14692	A	A
Compressive Strength							
E-Modulus							
Physical Measurement	3.723	3.727	3.723	3.723	3.724		

15448
3437
22.2%
23.5%

PT3-#5-4-D	1	2	3	4	5	6	7
Transmission Time	21.2	22	21.6	20.7	19.9		
Distance	.31	.310	.310	.310	.310		
Pulse Velocity	14623	14091	14352	14976	15578	N	N
Compressive Strength						A	A
E-Modulus							
Physical Measurement	3.715	3.71[illegible]5	3.719[illegible]7	3.718	3.720		

14724
3543
24%
26%

PT Z-S-[illegible]3D	1	2	3	4	5	6	7
Transmission Time	19.5	20.1	20.2	19.8	19.8		
Distance	.31	.31	.310	.310	.311		
Pulse Velocity	15897	15423	15423	15657	15657		
Compressive Strength							
E-Modulus							
Physical Measurement	3.720	3.720	3.722	3.723	3.729		

15611
3917
25%
27%

In Distance

A-D Ave 23.06%
Ave B-D - 25.25%

1/13/17 H area concrete

Rebar embedded at position #3

PT3-S-4-CC	1	2	3	4	5	6	7	
Transmission Time	22.2 μs	21.4	22.1					
Distance	0.3098	0.310	0.3103					
Pulse Velocity	13964	14486	14027					
Compressive Strength								
E-Modulus								
Physical Measurement	3.717	3.720	3.724					
PT3-N-2-B	1	2	3	4	5	6	7	
Transmission Time	38.9	37.9	39.3	39.8	39.6	40.9	37.5	
Distance	0.473	0.473	0.474	0.4745	0.473	0.473	0.473	
Pulse Velocity	12159	12480	12092	11935	11944	11795	12613	
Compressive Strength								
E-Modulus								
Physical Measurement	5.675	5.680	5.689	5.694	5.680	5.670	5.675	
	8	9	10	4	5	6	7	
Transmission Time	38.3	41.4	43.5					
Distance	0.473	0.473	0.472					
Pulse Velocity	12350	11425	10851					11964 Ave
Compressive Strength								
E-Modulus								
Physical Measurement	5.680	5.678	5.672					
PT3-N-1-13	1	2	3	4	5	6	7	
Transmission Time	25.7	22.5	22.5	22.5	22.9	23.8		
Distance	0.311	0.311	0.311	0.311	0.311	0.311		
Pulse Velocity	12101	13822	13822	13822	13463	13067		13349
Compressive Strength								
E-Modulus								
Physical Measurement	3.726	3.730	3.730	3.730	3.730	3.732		
	1	2	3	4	5	6	7	
Transmission Time								
Distance								
Pulse Velocity								
Compressive Strength								
E-Modulus								
Physical Measurement								
	1	2	3	4	5	6	7	
Transmission Time								
Distance								
Pulse Velocity								
Compressive Strength								
E-Modulus								
Physical Measurement								

24.7
23.7
13122

C-Core

1-724-512-0330
JoE-Forelley

Ar - Personnel Tunnel #3 221-H South Wall

PT3-S-2-D	1	2	3	4	5	6	7	
Transmission Time	20.8	19.3	20.5	20.2	19.2			
Distance	.310	.310	.310	.310	.310			
Pulse Velocity	14904	16062	15271	15347	16146	N	N	15546
Compressive Strength						A	A	3280
E-Modulus								21 %
Physical Measurement	3.720	3.720	3.727	3.728	3.728			23.25 %
PT3-S-6-D	1	2	3	4	5	6	7	
Transmission Time	19.7	19.9	19.5	19.3	19.6			
Distance	.31	.311	.311	.311	.310			
Pulse Velocity	15736	15578	16114	16114	15816	N	N	15871
Compressive Strength						A	A	4070
E-Modulus								25 %
Physical Measurement	3.724	3.730	3.730	3.730	3.725			28.4 %
PT3-S-1-D	1	2	3	4	5	6	7	
Transmission Time	19.2	20.5	21	21	20.[illegible]	20.2	20.1	15297
Distance	.311	.311	.311	.311	.312	.312	.312	3243
Pulse Velocity	16198	15171	14810	14810	15171	15396	15522	
Compressive Strength								21.2 %
E-Modulus								23.57 %
Physical Measurement	3.734	3.732	3.736	3.757	3.740	3.740	3.740	
PT3-S-5-D	1	2	3	4	5	6	7	
Transmission Time	21.7	18.7	18.8	20.4	21.1			15448
Distance	.310	.311	.310	.310	.310	N	N	3457
Pulse Velocity	14286	16578	16489	15196	14692	A	A	22.2 %
Compressive Strength								
E-Modulus								23.3 %
Physical Measurement	3.723	3.727	3.723	3.723	3.724			
PT3-S-4-D	1	2	3	4	5	6	7	
Transmission Time	21.2	22	21.6	20.7	19.9			
Distance	.31	.310	.310	.310	.310			
Pulse Velocity	14623	14091	14352	14976	15578	N	N	14724
Compressive Strength						A	A	3543
E-Modulus								24 %
Physical Measurement	3.715	3.715	3.717	3.718	3.720			26 %
PT3-S-3D	1	2	3	4	5	6	7	
Transmission Time	19.5	20.1	20.2	19.8	19.8			15611
Distance	.31	.31	.310	.310	.311			3917
Pulse Velocity	15897	15423	15423	15657	15657			
Compressive Strength								25 %
E-Modulus								27 %
Physical Measurement	3.720	3.720	3.722	3.723	3.729			

In Distance

A-D Ave 23.06 %
Ave B-D = 25.25 %

24.7
23.7
13122

LC-Core

1-724-512-0330
JOE-Forcelli

PT - Personnel Tunnel #3 221-H South Wall

PT3-S-2-D	1	2	3	4	5	6	7	
Transmission Time	20.8	19.3	20.3	20.2	19.2			
Distance	.310	.310	.310	.310	.310			
Pulse Velocity	14904	16062	15271	15347	16146	N/A	N/A	15546
Compressive Strength								3280
E-Modulus								21 %
Physical Measurement	3.720	3.720	3.727	3.728	3.728			23.25 %
PT3-S-6-D	1	2	3	4	5	6	7	
Transmission Time	19.7	19.9	19.3	19.3	19.6			
Distance	.31	.311	.311	.311	.310			
Pulse Velocity	15736	15578	16114	16114	15816	N/A	N/A	15871
Compressive Strength								4070
E-Modulus								25%
Physical Measurement	3.724	3.730	3.730	3.730	3.725			28.4%
PT3-S-1-D	1	2	3	4	5	6	7	
Transmission Time	19.2	20.5	21	21	20.[illegible]	20.2	20.1	15297
Distance	.311	.311	.311	.311	.312	.312	.312	3243
Pulse Velocity	16198	15171	14810	14810	15171	15396	15522	
Compressive Strength								21.2%
E-Modulus								23.57%
Physical Measurement	3.734	3.732	3.736	3.737	3.740	3.740	3.740	
PT3-S-5-D	1	2	3	4	5	6	7	
Transmission Time	21.7	18.7	18.8	20.4	21.1			15448
Distance	.310	.311	.310	.310	.310	N/A	N/A	3437
Pulse Velocity	14286	16578	16489	15196	14692			
Compressive Strength								22.2%
E-Modulus								23.5%
Physical Measurement	3.723	3.727	3.723	3.723	3.724			
PT3-S-4-D	1	2	3	4	5	6	7	
Transmission Time	21.2	22	21.6	20.7	19.9			
Distance	.31	.310	.310	.310	.310			
Pulse Velocity	14623	14091	14352	14976	15578	N/A	N/A	14724
Compressive Strength								3543
E-Modulus								24%
Physical Measurement	3.715	3.715	3.717	3.718	3.720			26%
PT3-S-3D	1	2	3	4	5	6	7	
Transmission Time	19.5	20.1	20.2	19.8	19.8			15611
Distance	.31	.31	.310	.310	.31			3917
Pulse Velocity	15897	15423	15423	15657	15657			
Compressive Strength								25%
E-Modulus								27%
Physical Measurement	3.720	3.720	3.722	3.723	3.729			

In Distance

A-D Ave 23.06%
Ave B-D - 25.25%

Appendix G. Non-Radiologically Contaminated South Wall Concrete Cores - Compressive Strength, Porosity, and Density Data Sheets

Appendix G. Non-Radiologically Contaminated South Wall Concrete Cores - Compressive Strength, Porosity, and Density Data Sheets

ASR 18-203 (04/13)

URS

Savannah River Site

Summary Report of Testing Activities

☐ Report ☒ Cover Sheet

Page 1 of 3

Approvals (If required)	
Senior Civil Technician (Level III): Charles A. Bookhamer	**Work Package No.:** 1525456
	QCIR No.: N/A
	Project No.: N/A
Civil Testing & Inspection Superintendent: W. Pope, Jr.	**Design Category:** GS
	Report No.: 2016-CAEX-0001 **Date:** 11-15-16
Lab. No.: 160088	**Test Method:** See attached pages
Discipline: Civil	**Description:** Concrete
Location: 221H Personnel Tunnel 3 South Wall	**Reported to:** J. Carter, 8-1727

Summary: This report presents the data required by the H-Area CAEX Tunnel Concrete Core Sampling Plan, C-ESR-H-00044, Revision 0. Page 2 contains a spreadsheet for data and results provided by the calculations of ASTM C642-13 covering the determination of density, percent absorption, and percent voids in hardened concrete. Lines 1 and 2 on page 2 reference Sample IDs 221H-PT3-S-1A and 221H-PT3-S-1B for this report. These samples are undersized and the data is provided for Information Only.

See page 3 for the results of "Compressive Strength of Drilled Cores". Also note, the densities of the core segments are provided in the page 3 Remarks Section.

All information in this report is from core segments from sample location 221H-PT3-S-1.

N A

M&TE: See attached pages **Cal. Due Date:** See attached pages	**Procedure:** C-QCP-002
NCR No.: N/A	**Rev.:** 0
Test Results: ☐ Conforming ☐ Nonconforming ☒* N/A	**PCN(s):** N/A
Remarks: * For engineering evaluation N/A N/A N/A	**Spec.:** C-ERS-H-00044
	Rev.: 0
	DCF(s): N/A

Technician (Print/Sign): Charles A. Bookhamer/ Charles A. Bookhamer **Level:** III **Date:** 12-13-16

Reviewer (Print/Sign): Charles Z. Moore/ C Z Moore **Level:** II **Date:** 12-14-16

THIS REPORT SHALL NOT BE REPRODUCED, EXCEPT IN FULL, WITHOUT THE WRITTEN APPROVAL OF THE LABORATORY. 12-15-16

ASR 18-250 (04/13)

URS

Savannah River Site

Summary Report of Testing Activities (Continuation Sheet)

Report Title: 221H Personnel Tunnel 3 South Wall **Report No.:** 2016-CAEX-0001

Item #	Summary

Density, Absorption, and Voids in Hardened Concrete

A = mass of oven-dried sample in air [g]
B = mass of surface-dry sample in air after immersion [g]
C = mass of surface-dry sample in air after immersion and boiling [g]
D = apparent mass of sample in water after immersion and boiling [g]
g_1 = bulk density, dry, Mg/m^3, or g/cm^3
g_2 = aparent bulk density, Mg/m^3, or g/cm^3
ρ = density of water = 1 Mg/m^3 = 1 g/cm^3

AAI = Absorption after immersion [%]
AAIB = Absorption after immersion and boiling [g]
g_1 = Bulk density, dry
BDAI = Bulk density after immersion
BDAIB = Bulk density after immersion and boiling
g_2 = Apparent Density
VPP = Volume of permeable pore speac (voids) [%]

		A	B	C	D	g_1	g_2	ρ	AAI	AAIB	BDAI	BDAIB	VPP
Line	Sample ID	[g]	[g]	[g]	[g]	[g/cm³]	[g/cm³]	[g/cm³]	[%]	[%]	[g/cm³]	[g/cm³]	[%]
1	*221H-PT3-S-1A	440.51	466.80	469.71	274.4	2.26	2.65	1.00	6.0	6.6	2.39	2.40	15.0
2	*221H-PT3-S-1B	442.75	473.57	475.94	275.1	2.20	2.64	1.00	7.0	7.5	2.36	2.37	16.5
3	221H-PT3-S-2A	1203.44	1296.86	1307.48	747.0	2.15	2.64	1.00	7.8	8.6	2.31	2.33	18.6
4	*221H-PT3-S-2C	741.60	796.10	802.03	460.5	2.17	2.64	1.00	7.3	8.1	2.33	2.35	17.7
5	221H-PT3-S-3CC	1099.22	1175.48	1179.36	680.4	2.20	2.62	1.00	6.9	7.3	2.36	2.36	16.1
6	221H-PT3-S-4CC	1329.62	1437.36	1449.57	823.6	2.12	2.63	1.00	8.1	9.0	2.30	2.32	19.2
7	221H-PT3-S-5CC	1332.80	1440.20	1451.20	825.2	2.13	2.63	1.00	8.1	8.9	2.30	2.32	18.9
8	221H-PT3-S-6CC	1216.33	1306.20	1312.65	752.2	2.17	2.62	1.00	7.4	7.9	2.33	2.34	17.2

* Undersized Sample

Absorption after immersion [%]	% = [(B-A)/A] X 100
Absorption after immersion and boiling [g]	% = [(C-A)/A] X 100
Bulk density, dry	g_1 = [A/(C-D)] X ρ
Bulk density after immersion	BDAI = [B/(C-D)] X ρ
Bulk density after immersion and boiling	BDAIB = [C/(C-D)] X ρ
Apparent Density	g_2 = [A/(A-D)] X ρ
Volume of permeable pore space (voids) [%]	% = (g_2 - g_1)/g_2 x 100

Comments:

 12-15-16

ASR 18-202 (4/13)

URS

Savannah River Site

Compressive Strength of Drilled Cores

ASTM C 39-(14) ASTM C 42-(13) ASTM C 617-(12)

Report No.: 2016-CAEX-0001 **Project No.:** N/A **Work Package No.:** 1525456 **Design Cat.:** GS

QCIR No.: N/A **Date & Time Core Taken:** 11-15-16 @ N/A **Concrete Supplier:** N/A **Placement Date:** 1952

Placement Location: 221H- Section 3, Personnel Tunnel South Wall **Mix Design:** N/A **Design Strength:** 2500 psi @ N/A Days

Lab. Number	Days Aged	Date Tested	Length Before Capping, in.	Length After Capping, in.	Average Diameter, in.	Area, sq.in.	Total Load, lbs.	Length to Diameter Ratio	Correction Factor	Unit Load, psi	Corrected psi	Technician Init./Level
160088	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
S-1-A	7	11-23-16	6.98	7.23	3.73	10.93	23524	1.94	1.00	2150	N/A	CAB/III
S-1-B	7	11-23-16	6.94	7.22	3.72	10.87	36709	1.94	1.00	3380	N/A	CAB/III
S-1-C	7	11-23-16	7.56	7.80	3.71	10.81	41033	2.10	1.00	3800	N/A	CAB/III
S-1-Spare	7	11-23-16	7.51	7.73	3.72	10.87	39549	2.07	1.00	3640	N/A	CAB/III
						N	A					

Direction of Application of the Load on the Specimen with Respect to the Horizontal Plane of the Concrete Placed: N/A

Nominal Maximum Size of Aggregate: N/A **Method of Test:** N/A

M&TE: 1) CA-002; 2) TM-5

Cal. Due Date: 1) 9-23-17; 2) 1-12-17

Test Results: ☐ Conforming ☐ Nonconforming ☒ *X N/A

NCR No.: N/A

Procedure: C-QCP-002 **Rev.:** 0 **PCN(s):** N/A

Remarks: *For Engineering Evaluation. Density of Cores follows:
221H-PT3-S-1-A = 143 pcf; 221H-PT3-S-1-B = 145 pcf; 221H-PT3-S-1-C = 145 pcf;
221H-PT3-S-1-Spare = 143 pcf

Spec.: C-ESR-H-00044 **Rev.:** 0 **DCF(s):** N/A

Dwg(s): N/A **Rev.:** N/A **DCF(s):** N/A

Technician (Print/Sign): Charles A. Bookhamer/ Charles A. Bookhamer **Level:** III **Date:** 11-23-16

Reviewer (Print/Sign): Charles Z. Moore/ C Z Moore **Level:** II **Date:** 12-14-16

ASR 18-203 (04/13)

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Savannah River Site

Summary Report of Testing Activities

☐ Report ☒ Cover Sheet

Approvals (If required)	Work Package No.: 1525456
Senior Civil Technician (Level III): Charles A. Bookhamer	QCIR No.: N/A Project No.: N/A
Civil Testing & Inspection Superintendent: W. Pope, Jr.	Design Category: GS Report No.: 2016-CAEX-0002 Date: 11-16-16
Lab. No.: 160089	Test Method: See attached pages
Discipline: Civil	Description: Concrete
Location: 221H Personnel Tunnel 3 South Wall	Reported to: J. Carter, 8-1727

Summary: This report presents the data required by the H-Area CAEX Tunnel Concrete Core Sampling Plan, C-ESR-H-00044, Revision 0. Page 2 contains a spreadsheet for data and results provided by the calculations of ASTM C642-13 covering the determination of density, percent absorption, and percent voids in hardened concrete. Lines 3 and 4 on page 2 reference Sample IDs 221H-PT3-S-2A and 221H-PT3-S-2C for this report. Note that Sample 221H-PT3-S-2C is undersized and the data is provided for Information Only.
See page 3 for the results of "Compressive Strength of Drilled Cores". Also note, the densities of the core segments are provided in the page 3 Remarks Section.
All information in this report is from core segments from sample location 221H-PT3-S-2.

N A

M&TE: See attached pages	Cal. Due Date: See attached pages	Procedure: C-QCP-002
NCR No.: N/A		Rev.: 0
Test Results: ☐ Conforming ☐ Nonconforming ☒ *X N/A		PCN(s): N/A
Remarks: * For engineering evaluation N/A N/A N/A		Spec.: C-ERS-H-00044 Rev.: 0 DCF(s): N/A

Technician (Print/Sign): Charles A. Bookhamer/ [signature] Level: III Date: 12-13-16

Reviewer (Print/Sign): Charles Z. Moore/ [signature] Level: II Date: 12-14-16

12-15-16

ASR 18-250 (04/13)

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Savannah River Site

Summary Report of Testing Activities (Continuation Sheet)

Report Title: 221H Personnel Tunnel 3 South Wall **Report No.:** 2016-CAEX-0002

Item #	Summary

Density, Absorption, and Voids in Hardened Concrete

A = mass of oven-dried sample in air [g]
B = mass of surface-dry sample in air after immersion [g]
C = mass of surface-dry sample in air after immersion and boiling [g]
D = apparent mass of sample in water after immersion and boiling [g]
g_1 = bulk density, dry, Mg/m^3, or g/cm^3
g_2 = aparent bulk density, Mg/m^3, or g/cm^3
ρ = density of water = 1 Mg/m^3 = 1 g/cm^3

AAI = Absorption after immersion [%]
AAIB = Absorption after immersion and boiling [g]
g_1 = Bulk density, dry
BDAI = Bulk density after immersion
BDAIB = Bulk density after immersion and boiling
g_2 = Apparent Density
VPP = Volume of permeable pore speac (voids) [%]

		A	B	C	D	g_1	g_2	ρ	AAI	AAIB	BDAI	BDAIB	VPP
Line	Sample ID	[g]	[g]	[g]	[g]	[g/cm^3]	[g/cm^3]	[g/cm^3]	[%]	[%]	[g/cm^3]	[g/cm^3]	[%]
1	*221H-PT3-S-1A	440.51	466.80	469.71	274.4	2.26	2.65	1.00	6.0	6.6	2.39	2.40	15.0
2	*221H-PT3-S-1B	442.75	473.57	475.94	275.1	2.20	2.64	1.00	7.0	7.5	2.36	2.37	16.5
3	221H-PT3-S-2A	1203.44	1296.86	1307.48	747.0	2.15	2.64	1.00	7.8	8.6	2.31	2.33	18.6
4	*221H-PT3-S-2C	741.60	796.10	802.03	460.5	2.17	2.64	1.00	7.3	8.1	2.33	2.35	17.7
5	221H-PT3-S-3CC	1099.22	1175.48	1179.36	680.4	2.20	2.62	1.00	6.9	7.3	2.36	2.36	16.1
6	221H-PT3-S-4CC	1329.62	1437.36	1449.57	823.6	2.12	2.63	1.00	8.1	9.0	2.30	2.32	19.2
7	221H-PT3-S-5CC	1332.80	1440.20	1451.20	825.2	2.13	2.63	1.00	8.1	8.9	2.30	2.32	18.9
8	221H-PT3-S-6CC	1216.33	1306.20	1312.65	752.2	2.17	2.62	1.00	7.4	7.9	2.33	2.34	17.2

* Undersized Sample

Absorption after immersion [%]	% = [(B-A)/A] X 100
Absorption after immersion and boiling [g]	% = [(C-A)/A] X 100
Bulk density, dry	g_1 = [A/(C-D)] X ρ
Bulk density after immersion	BDAI = [B/(C-D)] X ρ
Bulk density after immersion and boiling	BDAIB = [C/(C-D)] X ρ
Apparent Density	g_2 = [A/(A-D)] X ρ
Volume of permeable pore space (voids) [%]	% = (g_2 - g_1)/g_2 x 100

Comments: N/A

12-15-16

ASR 18-202 (4/13)

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Savannah River Site

Compressive Strength of Drilled Cores

ASTM C 39-(14) ASTM C 42-(13) ASTM C 617-(12)

Report No.: 2016-CAEX-0002 Project No.: N/A Work Package No.: 1525456 Design Cat.: GS

QCIR No.: N/A Date & Time Core Taken: 11-16-16 @ N/A Concrete Supplier: N/A Placement Date: N/A

Placement Location: 221H- Section 3, Personnel Tunnel South Wall Mix Design: N/A Design Strength: 2500 psi @ N/A Days

Lab. Number	Days Aged	Date Tested	Length Before Capping, in.	Length After Capping, in.	Average Diameter, in.	Area, sq.in.	Total Load, lbs.	Length to Diameter Ratio	Correction Factor	Unit Load, psi	Corrected psi	Technician Init./Level
160089	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
S-2-B	7	11-23-16	5.59	5.83	3.73	10.93	29654	1.56	0.96	2720	2610	CAB/III
S-2-BB	7	11-23-16	7.12	7.29	3.72	10.87	41399	1.96	1.00	3810	N/A	CAB/III
S-2-C	7	11-23-16	7.02	7.17	3.72	10.87	37201	1.93	1.00	3420	N/A	CAB/III
						N	A					

Direction of Application of the Load on the Specimen with Respect to the Horizontal Plane of the Concrete Placed: N/A

Nominal Maximum Size of Aggregate: N/A Method of Test: N/A

M&TE: 1) CA-002; 2) TM-5	Cal. Due Date: 1) 9-23-17; 2) 1-12-17
Test Results: ☐ Conforming ☐ Nonconforming ☒ *X N/A	NCR No.: N/A
Remarks: *For Engineering Evaluation. Density of Cores follows: 221H-PT3-S-2-BB = 142 pcf; 221H-PT3-S-2-C = 142 pcf	Procedure: C-QCP-002 Rev.: 0 PCN(s): N/A
	Spec.: C-ESR-H-00044 Rev.: 0 DCF(s): N/A
221H-PT3-S-2-B was for information only because of L/D Ratio Correction Factor applied.	Dwg(s): N/A Rev.: N/A DCF(s): N/A

Technician (Print/Sign): Charles A. Bookhamer/ Charles A. Bookhamer Level: III Date: 11-23-16

Reviewer (Print/Sign): Charles Z. Moore/ C Z. M Level: II Date: 12-14-16

THIS REPORT SHALL NOT BE REPRODUCED, EXCEPT IN FULL, WITHOUT THE WRITTEN APPROVAL OF THE LABORATORY.

ASR 18-203 (04/13)

URS
Savannah River Site
Summary Report of Testing Activities

☐ Report ☒ Cover Sheet — Page 1 of 3

Approvals (If required)	Work Package No.: 1525456
Senior Civil Technician (Level III): Charles A. Bookhamer	QCIR No.: N/A Project No.: N/A
Civil Testing & Inspection Superintendent: W. Pope, Jr.	Design Category: GS Report No.: 2016-CAEX-0003 — Date: 11-17-16
Lab. No.: 160090	Test Method: See attached pages
Discipline: Civil	Description: Concrete
Location: 221H Personnel Tunnel 3 South Wall	Reported to: J. Carter, 8-1727

Summary: This report presents the data required by the H-Area CAEX Tunnel Concrete Core Sampling Plan, C-ESR-H-00044, Revision 0. Page 2 contains a spreadsheet for data and results provided by the calculations of ASTM C642-13 covering the determination of density, percent absorption, and percent voids in hardened concrete.
Line 5 on page 2 references Sample ID 221H-PT3-S-3CC for this report.
See page 3 for the results of "Compressive Strength of Drilled Cores". Also note, the densities of the core segments are provided in the page 3 Remarks Section.
All information in this report is from core segments from sample location 221H-PT3-S-3.

N A

M&TE: See attached pages — Cal. Due Date: See attached pages	Procedure: C-QCP-002
NCR No.: N/A	Rev.: 0
Test Results: ☐ Conforming ☐ Nonconforming ☒* N/A	PCN(s): N/A
Remarks: * For engineering evaluation	Spec.: C-ERS-H-00044
N/A	Rev.: 0
N/A N/A	DCF(s): N/A

Technician (Print/Sign): Charles A. Bookhamer/ [signature] Level: III Date: 12-13-16

Reviewer (Print/Sign): Charles Z. Moore/ [signature] Level: II Date: 12-14-16

THIS REPORT SHALL NOT BE REPRODUCED, EXCEPT IN FULL, WITHOUT THE WRITTEN APPROVAL OF THE LABORATORY.

12-15-16

ASR 18-250 (04/13)

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Savannah River Site

Summary Report of Testing Activities (Continuation Sheet)

Report Title: 221H Personnel Tunnel 3 South Wall **Report No.:** 2016-CAEX-0003

Item #	Summary

Density, Absorption, and Voids in Hardened Concrete

A = mass of oven-dried sample in air [g]
B = mass of surface-dry sample in air after immersion [g]
C = mass of surface-dry sample in air after immersion and boiling [g]
D = apparent mass of sample in water after immersion and boiling [g]
g_1 = bulk density, dry, Mg/m^3, or g/cm^3
g_2 = aparent bulk density, Mg/m^3, or g/cm^3
ρ = density of water = 1 Mg/m^3 = 1 g/cm^3

AAI = Absorption after immersion [%]
AAIB = Absorption after immersion and boiling [g]
g_1 = Bulk density, dry
BDAI = Bulk density after immersion
BDAIB = Bulk density after immersion and boiling
g_2 = Apparent Density
VPP = Volume of permeable pore speac (voids) [%]

Line	Sample ID	A [g]	B [g]	C [g]	D [g]	g_1 [g/cm^3]	g_2 [g/cm^3]	ρ [g/cm^3]	AAI [%]	AAIB [%]	BDAI [g/cm^3]	BDAIB [g/cm^3]	VPP [%]
1	*221H-PT3-S-1A	440.51	466.80	469.71	274.4	2.26	2.65	1.00	6.0	6.6	2.39	2.40	15.0
2	*221H-PT3-S-1B	442.75	473.57	475.94	275.1	2.20	2.64	1.00	7.0	7.5	2.36	2.37	16.5
3	221H-PT3-S-2A	1203.44	1296.86	1307.48	747.0	2.15	2.64	1.00	7.8	8.6	2.31	2.33	18.6
4	*221H-PT3-S-2C	741.60	796.10	802.03	460.5	2.17	2.64	1.00	7.3	8.1	2.33	2.35	17.7
5	221H-PT3-S-3CC	1099.22	1175.48	1179.36	680.4	2.20	2.62	1.00	6.9	7.3	2.36	2.36	16.1
6	221H-PT3-S-4CC	1329.62	1437.36	1449.57	823.6	2.12	2.63	1.00	8.1	9.0	2.30	2.32	19.2
7	221H-PT3-S-5CC	1332.80	1440.20	1451.20	825.2	2.13	2.63	1.00	8.1	8.9	2.30	2.32	18.9
8	221H-PT3-S-6CC	1216.33	1306.20	1312.65	752.2	2.17	2.62	1.00	7.4	7.9	2.33	2.34	17.2

* Undersized Sample

Absorption after immersion [%]	% = [(B-A)/A] X 100
Absorption after immersion and boiling [g]	% = [(C-A)/A] X 100
Bulk density, dry	g_1 = [A/(C-D)] X ρ
Bulk density after immersion	BDAI = [B/(C-D)] X ρ
Bulk density after immersion and boiling	BDAIB = [C/(C-D)] X ρ
Apparent Density	g_2 = [A/(A-D)] X ρ
Volume of permeable pore space (voids) [%]	% = (g_2 - g_1)/g_2 x 100

Comments:

12-15-16

ASR 18-202 (4/13)

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Savannah River Site

Compressive Strength of Drilled Cores

ASTM C 39-(14) ASTM C 42-(13) ASTM C 617-(12)

Report No.: 2016-CAEX-0003 **Project No.:** N/A **Work Package No.:** 1525456 **Design Cat.:** GS

QCIR No.: N/A **Date & Time Core Taken:** 11-17-16 @ N/A **Concrete Supplier:** N/A **Placement Date:** N/A

Placement Location: 221H- Section 3, Personnel Tunnel South Wall **Mix Design:** N/A **Design Strength:** 2500 psi @ N/A Days

Lab. Number	Days Aged	Date Tested	Length Before Capping, in.	Length After Capping, in.	Average Diameter, in.	Area, sq.in.	Total Load, lbs.	Length to Diameter Ratio	Correction Factor	Unit Load, psi	Corrected psi	Technician Init./Level
160090	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
S-3-A	6	11-23-16	7.18	7.35	3.73	10.93	36149	1.97	1.00	3310	N/A	CAB/III
S-3-B	6	11-23-16	7.29	7.45	3.72	10.87	42346	2.00	1.00	3900	N/A	CAB/III
S-3-C	6	11-23-16	7.12	7.31	3.72	10.87	49344	1.97	1.00	4540	N/A	CAB/III
						N	A					

Direction of Application of the Load on the Specimen with Respect to the Horizontal Plane of the Concrete Placed: N/A

Nominal Maximum Size of Aggregate: N/A **Method of Test:** N/A

M&TE: 1) CA-002; 2) TM-5

Cal. Due Date: 1) 9-23-17; 2) 1-12-17

Test Results: ☐ Conforming ☐ Nonconforming ☒ *X N/A

NCR No.: N/A

Procedure: C-QCP-002 **Rev.:** 0 **PCN(s):** N/A

Remarks: *For Engineering Evaluation. Density of Cores follows:
221H-PT3-S-3-A = 141 pcf; 221H-PT3-S-3-B = 144 pcf; 221H-PT3-S-3-C = 144 pcf;
N/A

Spec.: C-ESR-H-00044 **Rev.:** 0 **DCF(s):** N/A

Dwg(s): N/A **Rev.:** N/A **DCF(s):** N/A

Technician (Print/Sign): Charles A. Bookhamer/ Charles A. Bookhamer **Level:** III **Date:** 11-23-16

Reviewer (Print/Sign): Charles Z. Moore/ C. Z. Moore **Level:** II **Date:** 12.14.16

THIS REPORT SHALL NOT BE REPRODUCED, EXCEPT IN FULL, WITHOUT THE WRITTEN APPROVAL OF THE LABORATORY

ASR 18-203 (04/13)

URS
Savannah River Site
Summary Report of Testing Activities

☐ Report ☒ Cover Sheet Page 1 of 3

Approvals (If required)	Work Package No.: 1525456
Senior Civil Technician (Level III): Charles A. Bookbamer	QCIR No.: N/A Project No.: N/A
Civil Testing & Inspection Superintendent: W. Pope, Jr.	Design Category: GS Report No.: 2016-CAEX-0004 Date: 11-21-16
Lab. No.: 160091	Test Method: See attached pages
Discipline: Civil	Description: Concrete
Location: 221H Personnel Tunnel 3 South Wall	Reported to: J. Carter, 8-1727

Summary: This report presents the data required by the H-Area CAEX Tunnel Concrete Core Sampling Plan, C-ESR-H-00044, Revision 0. Page 2 contains a spreadsheet for data and results provided by the calculations of ASTM C642-13 covering the determination of density, percent absorption, and percent voids in hardened concrete. Line 6 on page 2 references Sample ID 221H-PT3-S-4CC for this report.
See page 3 for the results of "Compressive Strength of Drilled Cores". Also note, the densities of the core segments are provided in the page 3 Remarks Section.
All information in this report is from core segments from sample location 221H-PT3-S-4.

N A

M&TE: See attached pages / Cal. Due Date: See attached pages	Procedure: C-QCP-002
NCR No.: N/A	Rev.: 0
Test Results: ☐ Conforming ☐ Nonconforming ☒* N/A	PCN(s): N/A
Remarks: * For engineering evaluation N/A N/A N/A	Spec.: C-ERS-H-00044 Rev.: 0 DCF(s): N/A
Technician (Print/Sign): Charles A. Bookhamer/ [signature]	Level: III Date: 12-13-16
Reviewer (Print/Sign): Charles Z. Moore/ [signature]	Level: II Date: 12-14-16

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ASR 18-250 (04/13)

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Savannah River Site

Page 2 of 3

Summary Report of Testing Activities (Continuation Sheet)

Report Title: 221H Personnel Tunnel 3 South Wall **Report No.:** 2016-CAEX-0004

Item #	Summary

Density, Absorption, and Voids in Hardened Concrete

A = mass of oven-dried sample in air [g]
B = mass of surface-dry sample in air after immersion [g]
C = mass of surface-dry sample in air after immersion and boiling [g]
D = apparent mass of sample in water after immersion and boiling [g]
g_1 = bulk density, dry, Mg/m^3, or g/cm^3
g_2 = aparent bulk density, Mg/m^3, or g/cm^3
ρ = density of water = 1 Mg/m^3 = 1 g/cm^3

AAI = Absorption after immersion [%]
AAIB = Absorption after immersion and boiling [g]
g_1 = Bulk density, dry
BDAI = Bulk density after immersion
BDAIB = Bulk density after immersion and boiling
g_2 = Apparent Density
VPP = Volume of permeable pore speac (voids) [%]

		A	B	C	D	g_1	g_2	ρ	AAI	AAIB	BDAI	BDAIB	VPP
Line	Sample ID	[g]	[g]	[g]	[g]	[g/cm^3]	[g/cm^3]	[g/cm^3]	[%]	[%]	[g/cm^3]	[g/cm^3]	[%]
1	*221H-PT3-S-1A	440.51	466.80	469.71	274.4	2.26	2.65	1.00	6.0	6.6	2.39	2.40	15.0
2	*221H-PT3-S-1B	442.75	473.57	475.94	275.1	2.20	2.64	1.00	7.0	7.5	2.36	2.37	16.5
3	221H-PT3-S-2A	1203.44	1296.86	1307.48	747.0	2.15	2.64	1.00	7.8	8.6	2.31	2.33	18.6
4	*221H-PT3-S-2C	741.60	796.10	802.03	460.5	2.17	2.64	1.00	7.3	8.1	2.33	2.35	17.7
5	221H-PT3-S-3CC	1099.22	1175.48	1179.36	680.4	2.20	2.62	1.00	6.9	7.3	2.36	2.36	16.1
6	221H-PT3-S-4CC	1329.62	1437.36	1449.57	823.6	2.12	2.63	1.00	8.1	9.0	2.30	2.32	19.2
7	221H-PT3-S-SCC	1332.80	1440.20	1451.20	825.2	2.13	2.63	1.00	8.1	8.9	2.30	2.32	18.9
8	221H-PT3-S-6CC	1216.33	1306.20	1312.65	752.2	2.17	2.62	1.00	7.4	7.9	2.33	2.34	17.2

* Undersized Sample

Absorption after immersion [%]	% = [(B-A)/A] X 100
Absorption after immersion and boiling [g]	% = [(C-A)/A] X 100
Bulk density, dry	g_1 = [A/(C-D)] X ρ
Bulk density after immersion	BDAI = [B/(C-D)] X ρ
Bulk density after immersion and boiling	BDAIB = [C/(C-D)] X ρ
Apparent Density	g_2 = [A/(A-D)] X ρ
Volume of permeable pore space (voids) [%]	% = (g_2 - g_1)/g_2 x 100

Comments:

THIS REPORT SHALL NOT BE REPRODUCED, EXCEPT IN FULL, WITHOUT THE WRITTEN APPROVAL OF THE LABORATORY.

12-15-16

ASR 18-202 (4/13)

URS
Savannah River Site
Compressive Strength of Drilled Cores

ASTM C 39-(14) ASTM C 42-(13) ASTM C 617-(12)

Report No.: 2016-CAEX-0004 **Project No.:** N/A **Work Package No.:** 1525456 **Design Cat.:** GS

QCIR No.: N/A **Date & Time Core Taken:** 11-21-16 @ N/A **Concrete Supplier:** N/A **Placement Date:** 1952

Placement Location: 221H- Section 3, Personnel Tunnel South Wall **Mix Design:** N/A **Design Strength:** 2500 psi @ N/A Days

Lab. Number	Days Aged	Date Tested	Length Before Capping, in.	Length After Capping, in.	Average Diameter, in.	Area, sq.in.	Total Load, lbs.	Length to Diameter Ratio	Correction Factor	Unit Load, psi	Corrected psi	Technician Init./Level
160091	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
S-4-A	6	11-29-16	7.15	7.32	3.73	10.93	32338	1.96	1.00	2960	N/A	CAB/III
S-4-B	6	11-29-16	7.20	7.76	3.72	10.87	40352	2.09	1.00	3710	N/A	CAB/III
S-4-C	6	11-29-16	7.24	7.51	3.73	10.93	43256	2.01	1.00	3960	N/A	CAB/III
						N	A					

Direction of Application of the Load on the Specimen with Respect to the Horizontal Plane of the Concrete Placed: N/A

Nominal Maximum Size of Aggregate: N/A **Method of Test:** N/A

M&TE: 1) CA-002; 2) TM-5

Cal. Due Date: 1) 9-23-17; 2) 1-12-17

Test Results: ☐ Conforming ☐ Nonconforming ☒ *X N/A

NCR No.: N/A

Procedure: C-QCP-002 **Rev.:** 0 **PCN(s):** N/A

Remarks: *For Engineering Evaluation. Density of Cores follows:
221H-PT3-S-4-A = 141 pcf; 221H-PT3-S-4-B = 140 pcf; 221H-PT3-S-4-C = 141 pcf;
N/A

Spec.: C-ESR-H-00044 **Rev.:** 0 **DCF(s):** N/A

Dwg(s): N/A **Rev.:** N/A **DCF(s):** N/A

Technician (Print/Sign): Charles A. Bookhamer/ Charles A. Bookhamer **Level:** III **Date:** 11-29-16

Reviewer (Print/Sign): Charles Z. Moore/ C Z Moore **Level:** II **Date:** 12-14-16

THIS REPORT SHALL NOT BE REPRODUCED, EXCEPT IN FULL, WITHOUT THE WRITTEN APPROVAL OF THE LABORATORY.

ASR 18-203 (04/13)

URS
Savannah River Site
Summary Report of Testing Activities

☐ Report ☒ Cover Sheet

Approvals (If required)	Work Package No.: 1525456
Senior Civil Technician (Level III): Charles A. Bookhamer	QCIR No.: N/A Project No.: N/A
Civil Testing & Inspection Superintendent: W. Pope, Jr.	Design Category: GS Report No.: 2016-CAEX-0005 Date: 11-22-16
Lab. No.: 160092	Test Method: See attached pages
Discipline: Civil	Description: Concrete
Location: 221H Personnel Tunnel 3 South Wall	Reported to: J. Carter, 8-1727

Summary: This report presents the data required by the H-Area CAEX Tunnel Concrete Core Sampling Plan, C-ESR-H-00044, Revision 0. Page 2 contains a spreadsheet for data and results provided by the calculations of ASTM C642-13 covering the determination of density, percent absorption, and percent voids in hardened concrete.
Line 7 on page 2 references Sample ID 221H-PT3-S-5CC for this report.
See page 3 for the results of "Compressive Strength of Drilled Cores". Also note, the densities of the core segments are provided in the page 3 Remarks Section.
All information in this report is from core segments from sample location 221H-PT3-S-5.

N A

M&TE: See attached pages · Cal. Due Date: See attached pages	Procedure: C-QCP-002
NCR No.: N/A	Rev.: 0
Test Results: ☐ Conforming ☐ Nonconforming ☒ * N/A	PCN(s): N/A
Remarks: * For engineering evaluation N/A N/A N/A	Spec.: C-ERS-H-00044 Rev.: 0 DCF(s): N/A
Technician (Print/Sign): Charles A. Bookhamer/ Charles A. Bookhamer	Level: III Date: 12-13-16
Reviewer (Print/Sign): Charles Z. Moore/ C. Z. Moore	Level: II Date: 12-14-16

 12-15-16

ASR 18-250 (04/13)

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Savannah River Site

Summary Report of Testing Activities (Continuation Sheet)

Report Title: 221H Personnel Tunnel 3 South Wall **Report No.:** 2016-CAEX-0005

Item #	Summary

Density, Absorption, and Voids in Hardened Concrete

A = mass of oven-dried sample in air [g]
B = mass of surface-dry sample in air after immersion [g]
C = mass of surface-dry sample in air after immersion and boiling [g]
D = apparent mass of sample in water after immersion and boiling [g]
g_1 = bulk density, dry, Mg/m^3, or g/cm^3
g_2 = aparent bulk density, Mg/m^3, or g/cm^3
ρ = density of water = 1 Mg/m^3 = 1 g/cm^3

AAI = Absorption after immersion [%]
AAIB = Absorption after immersion and boiling [g]
g_1 = Bulk density, dry
BDAI = Bulk density after immersion
BDAIB = Bulk density after immersion and boiling
g_2 = Apparent Density
VPP = Volume of permeable pore speac (voids) [%]

Line	Sample ID	A [g]	B [g]	C [g]	D [g]	g_1 [g/cm³]	g_2 [g/cm³]	ρ [g/cm³]	AAI [%]	AAIB [%]	BDAI [g/cm³]	BDAIB [g/cm³]	VPP [%]
1	*221H-PT3-S-1A	440.51	466.80	469.71	274.4	2.26	2.65	1.00	6.0	6.6	2.39	2.40	15.0
2	*221H-PT3-S-1B	442.75	473.57	475.94	275.1	2.20	2.64	1.00	7.0	7.5	2.36	2.37	16.5
3	221H-PT3-S-2A	1203.44	1296.86	1307.48	747.0	2.15	2.64	1.00	7.8	8.6	2.31	2.33	18.6
4	*221H-PT3-S-2C	741.60	796.10	802.03	460.5	2.17	2.64	1.00	7.3	8.1	2.33	2.35	17.7
5	221H-PT3-S-3CC	1099.22	1175.48	1179.36	680.4	2.20	2.62	1.00	6.9	7.3	2.36	2.36	16.1
6	221H-PT3-S-4CC	1329.62	1437.36	1449.57	823.6	2.12	2.63	1.00	8.1	9.0	2.30	2.32	19.2
7	221H-PT3-S-5CC	1332.80	1440.20	1451.20	825.2	2.13	2.63	1.00	8.1	8.9	2.30	2.32	18.9
8	221H-PT3-S-6CC	1216.33	1306.20	1312.65	752.2	2.17	2.62	1.00	7.4	7.9	2.33	2.34	17.2

* Undersized Sample

Absorption after immersion [%]	% = [(B-A)/A] X 100
Absorption after immersion and boiling [g]	% = [(C-A)/A] X 100
Bulk density, dry	g_1 = [A/(C-D)] X ρ
Bulk density after immersion	BDAI = [B/(C-D)] X ρ
Bulk density after immersion and boiling	BDAIB = [C/(C-D)] X ρ
Apparent Density	g_2 = [A/(A-D)] X ρ
Volume of permeable pore space (voids) [%]	% = (g_2 - g_1)/g_2 x 100

Comments: N/A

12-15-16

ASR 18-202 (4/13)

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Compressive Strength of Drilled Cores

ASTM C 39-(14) ASTM C 42-(13) ASTM C 617-(12)

Report No.: 2016-CAEX-0005 **Project No.:** N/A **Work Package No.:** 1525456 **Design Cat.:** GS

QCIR No.: N/A **Date & Time Core Taken:** 11-22-16 @ N/A **Concrete Supplier:** N/A **Placement Date:** 1952

Placement Location: 221H- Section 3, Personnel Tunnel South Wall **Mix Design:** N/A **Design Strength:** 2500 psi @ N/A Days

Lab. Number	Days Aged	Date Tested	Length Before Capping, in.	Length After Capping, in.	Average Diameter, in.	Area, sq.in.	Total Load, lbs.	Length to Diameter Ratio	Correction Factor	Unit Load, psi	Corrected psi	Technician Init./Level
160092	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
S-5-A	6	11-29-16	7.24	7.39	3.74	10.99	34100	1.98	1.00	3100	N/A	CAB / III
S-5-B	6	11-29-16	7.04	7.19	3.73	10.93	38912	1.93	1.00	3560	N/A	CAB / III
S-5-C	6	11-29-16	6.76	6.96	3.73	10.93	39872	1.87	1.00	3650	N/A	CAB / III
						N	A					

Direction of Application of the Load on the Specimen with Respect to the Horizontal Plane of the Concrete Placed: N/A

Nominal Maximum Size of Aggregate: N/A **Method of Test:** N/A

M&TE: 1) CA-002; 2) TM-5

Cal. Due Date: 1) 9-23-17; 2) 1-12-17

Test Results: ☐ Conforming ☐ Nonconforming ☒ *X N/A

NCR No.: N/A

Procedure: C-QCP-002 **Rev.:** 0 **PCN(s):** N/A

Remarks: *For Engineering Evaluation. Density of Cores follows:
221H-PT3-S-5-A = 138 pcf; 221H-PT3-S-5-B = 140 pcf; 221H-PT3-S-5-C = 140 pcf;
N/A

Spec.: C-ESR-H-00044 **Rev.:** 0 **DCF(s):** N/A

Dwg(s): N/A **Rev.:** N/A **DCF(s):** N/A

Technician (Print/Sign): Charles A. Bookhamer/ Charles A. Bookhamer **Level:** III **Date:** 11-29-16

Reviewer (Print/Sign): Charles Z. Moore/ Charles Z. Moore **Level:** II **Date:** 12-14-16

ASR 18-203 (04/13)

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Savannah River Site
Summary Report of Testing Activities

☐ Report ☒ Cover Sheet Page 1 of 3

Approvals (If required)	Work Package No.: 1525456
Senior Civil Technician (Level III): Charles A. Bookhamer	QCIR No.: N/A Project No.: N/A
Civil Testing & Inspection Superintendent: W. Pope, Jr.	Design Category: GS Report No.: 2016-CAEX-0006 Date: 11-23-16
Lab. No.: 160093	Test Method: See attached pages
Discipline: Civil	Description: Concrete
Location: 221H Personnel Tunnel 3 South Wall	Reported to: J. Carter, 8-1727

Summary: This report presents the data required by the H-Area CAEX Tunnel Concrete Core Sampling Plan, C-ESR-H-00044, Revision 0. Page 2 contains a spreadsheet for data and results provided by the calculations of ASTM C642-13 covering the determination of density, percent absorption, and percent voids in hardened concrete.
Line 8 on page 2 references Sample ID 221H-PT3-S-6CC for this report.
See page 3 for the results of "Compressive Strength of Drilled Cores". Also note, the densities of the core segments are provided in the page 3 Remarks Section.
All information in this report is from core segments from sample location 221H-PT3-S-6.

N A

M&TE: See attached pages	Cal. Due Date: See attached pages	Procedure: C-QCP-002
NCR No.: N/A		Rev.: 0
Test Results: ☐ Conforming ☐ Nonconforming ☒* N/A		PCN(s): N/A
Remarks: * For engineering evaluation N/A N/A N/A		Spec.: C-ERS-H-00044 Rev.: 0 DCF(s): N/A
Technician (Print/Sign): Charles A. Bookhamer/ Charles A. Bookhamer	Level: III	Date: 12-13-16
Reviewer (Print/Sign): Charles Z. Moore/ C Z. Moore	Level: II	Date: 12-14-16

 12-15-16

ASR 18-250 (04/13)

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Page 2 of 3

Summary Report of Testing Activities (Continuation Sheet)

Report Title: 221H Personnel Tunnel 3 South Wall **Report No.:** 2016-CAEX-0006

Item #	Summary

Density, Absorption, and Voids in Hardened Concrete

A = mass of oven-dried sample in air [g]
B = mass of surface-dry sample in air after immersion [g]
C = mass of surface-dry sample in air after immersion and boiling [g]
D = apparent mass of sample in water after immersion and boiling [g]
g_1 = bulk density, dry, Mg/m^3, or g/cm^3
g_2 = aparent bulk density, Mg/m^3, or g/cm^3
ρ = density of water = 1 Mg/m^3 = 1 g/cm^3

AAI = Absorption after immersion [%]
AAIB = Absorption after immersion and boiling [g]
g_1 = Bulk density, dry
BDAI = Bulk density after immersion
BDAIB = Bulk density after immersion and boiling
g_2 = Apparent Density
VPP = Volume of permeable pore speac (voids) [%]

		A	B	C	D	g_1	g_2	ρ	AAI	AAIB	BDAI	BDAIB	VPP
Line	Sample ID	[g]	[g]	[g]	[g]	[g/cm³]	[g/cm³]	[g/cm³]	[%]	[%]	[g/cm³]	[g/cm³]	[%]
1	*221H-PT3-S-1A	440.51	466.80	469.71	274.4	2.26	2.65	1.00	6.0	6.6	2.39	2.40	15.0
2	*221H-PT3-S-1B	442.75	473.57	475.94	275.1	2.20	2.64	1.00	7.0	7.5	2.36	2.37	16.5
3	221H-PT3-S-2A	1203.44	1296.86	1307.48	747.0	2.15	2.64	1.00	7.8	8.6	2.31	2.33	18.6
4	*221H-PT3-S-2C	741.60	796.10	802.03	460.5	2.17	2.64	1.00	7.3	8.1	2.33	2.35	17.7
5	221H-PT3-S-3CC	1099.22	1175.48	1179.36	680.4	2.20	2.62	1.00	6.9	7.3	2.36	2.36	16.1
6	221H-PT3-S-4CC	1329.62	1437.36	1449.57	823.6	2.12	2.63	1.00	8.1	9.0	2.30	2.32	19.2
7	221H-PT3-S-5CC	1332.80	1440.20	1451.20	825.2	2.13	2.63	1.00	8.1	8.9	2.30	2.32	18.9
8	221H-PT3-S-6CC	1216.33	1306.20	1312.65	752.2	2.17	2.62	1.00	7.4	7.9	2.33	2.34	17.2

* Undersized Sample

Absorption after immersion [%] — % = [(B-A)/A] X 100
Absorption after immersion and boiling [g] — % = [(C-A)/A] X 100
Bulk density, dry — g_1 = [A/(C-D)] X ρ
Bulk density after immersion — BDAI = [B/(C-D)] X ρ
Bulk density after immersion and boiling — BDAIB = [C/(C-D)] X ρ
Apparent Density — g_2 = [A/(A-D)] X ρ
Volume of permeable pore space (voids) [%] — % = (g_2 - g_1)/g_2 x 100

Comments:

NA

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12-15-16

ASR 18-202 (4/13)

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Compressive Strength of Drilled Cores

ASTM C 39-(14) ASTM C 42-(13) ASTM C 617-(12)

Report No.: 2016-CAEX-0006 **Project No.:** N/A **Work Package No.:** 1525456 **Design Cat.:** GS

QCIR No.: N/A **Date & Time Core Taken:** 11-23-16 @ N/A **Concrete Supplier:** N/A **Placement Date:** 1952

Placement Location: 221H- Section 3, Personnel Tunnel South Wall **Mix Design:** N/A **Design Strength:** 2500 psi @ N/A Days

Lab. Number	Days Aged	Date Tested	Length Before Capping, in.	Length After Capping, in.	Average Diameter, in.	Area, sq.in.	Total Load, lbs.	Length to Diameter Ratio	Correction Factor	Unit Load, psi	Corrected psi	Technician Init./Level
160093	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
S-6-A	7	11-30-16	7.18	7.35	3.74	10.99	36403	1.97	1.00	3310	N/A	CAB/III
S-6-B	7	11-30-16	7.19	7.45	3.74	10.99	47966	1.99	1.00	4360	N/A	CAB/III
S-6-C	7	11-30-16	7.28	7.45	3.73	10.93	49676	2.00	1.00	4540	N/A	CAB/III
S-6-CC	7	11-30-16	6.18	6.42	3.73	10.93	51804	1.72	.98	4740	4640	CAB/III
							A					
						N						

Direction of Application of the Load on the Specimen with Respect to the Horizontal Plane of the Concrete Placed: N/A

Nominal Maximum Size of Aggregate: N/A **Method of Test:** N/A

M&TE: 1) CA-002; 2) TM-5

Cal. Due Date: 1) 9-23-17; 2) 1-12-17

Test Results: ☐ Conforming ☐ Nonconforming ☒ *X N/A

NCR No.: N/A

Procedure: C-QCP-002 **Rev.:** 0 **PCN(s):** N/A

Spec.: C-ESR-H-00044 **Rev.:** 0 **DCF(s):** N/A

Dwg(s): N/A **Rev.:** N/A **DCF(s):** N/A

Remarks: *For Engineering Evaluation. Density of Cores follows:
221H-PT3-S-6-A = 138 pcf; 221H-PT3-S-6-B = 144 pcf; 221H-PT3-S-6-C = 144 pcf;
221H-PT3-S-6-CC was for information only because of L/D Ratio Correction Factor applied.

Technician (Print/Sign): Charles A. Bookhamer/ Charles A. Bookhamer **Level:** III **Date:** 11-30-16

Reviewer (Print/Sign): Charles Z. Moore/ C. Z. M **Level:** II **Date:** 12-14-16

12-15-16

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