NRC's Mesoscale Grout Monolith Experiments at the CNWRA

SwRI®/CNWRA® Investigators
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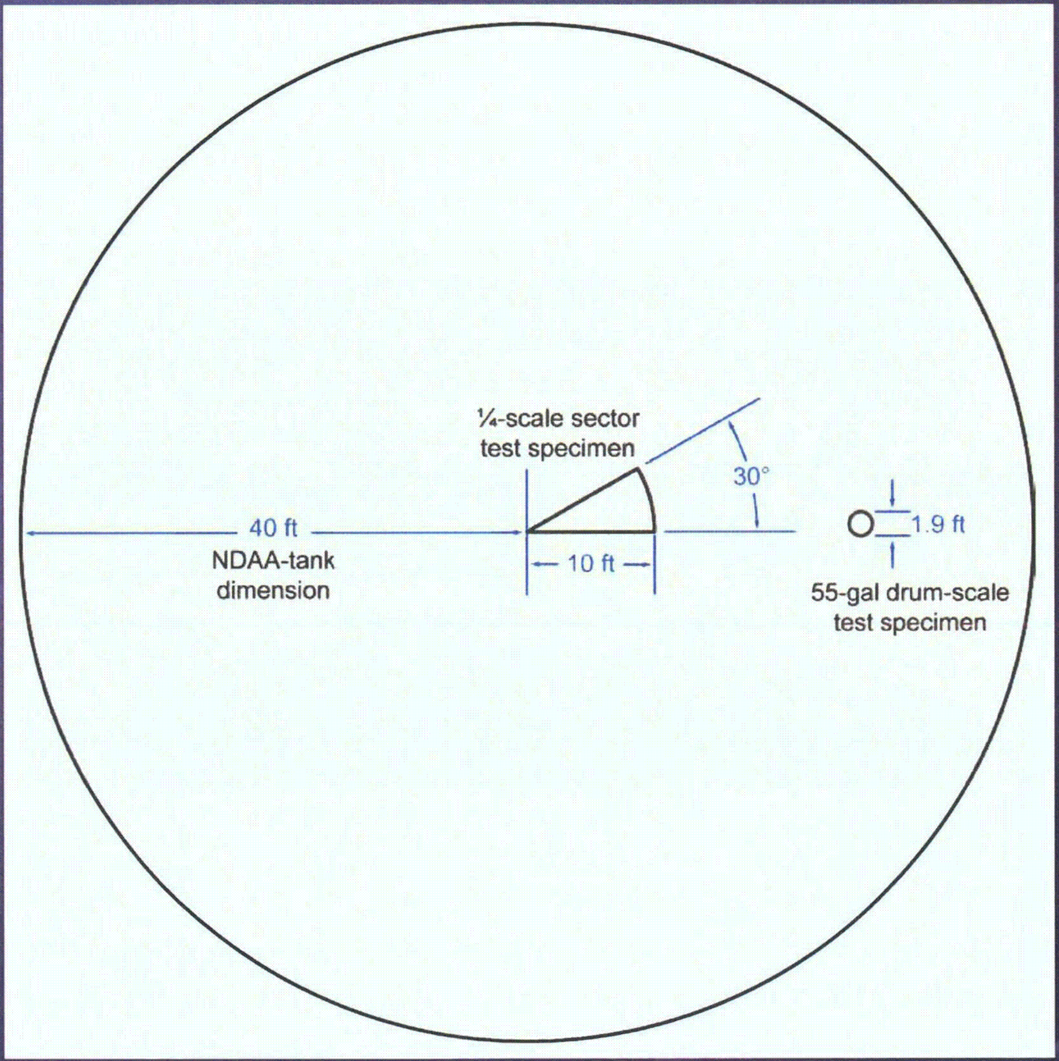
Mesoscale Specimen Dimensions



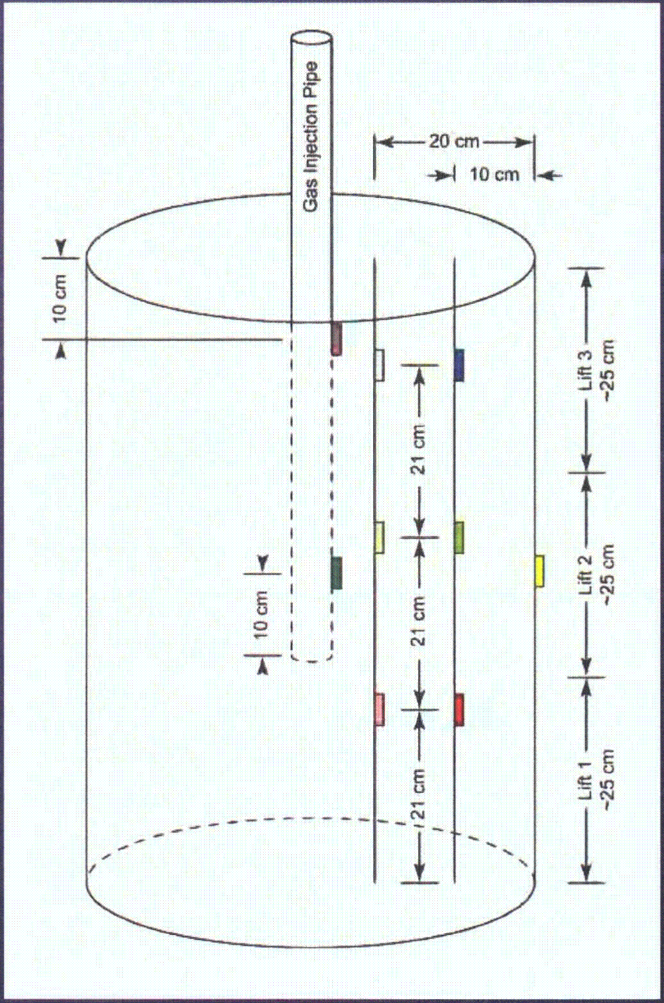
Thermal Expansion/Contraction Drum Specimen Matrix

Matrix of 55-gal Drum Test Specimens for Testing Thermal Expansion/Contraction Effects on Pipe–Grout Bonds.

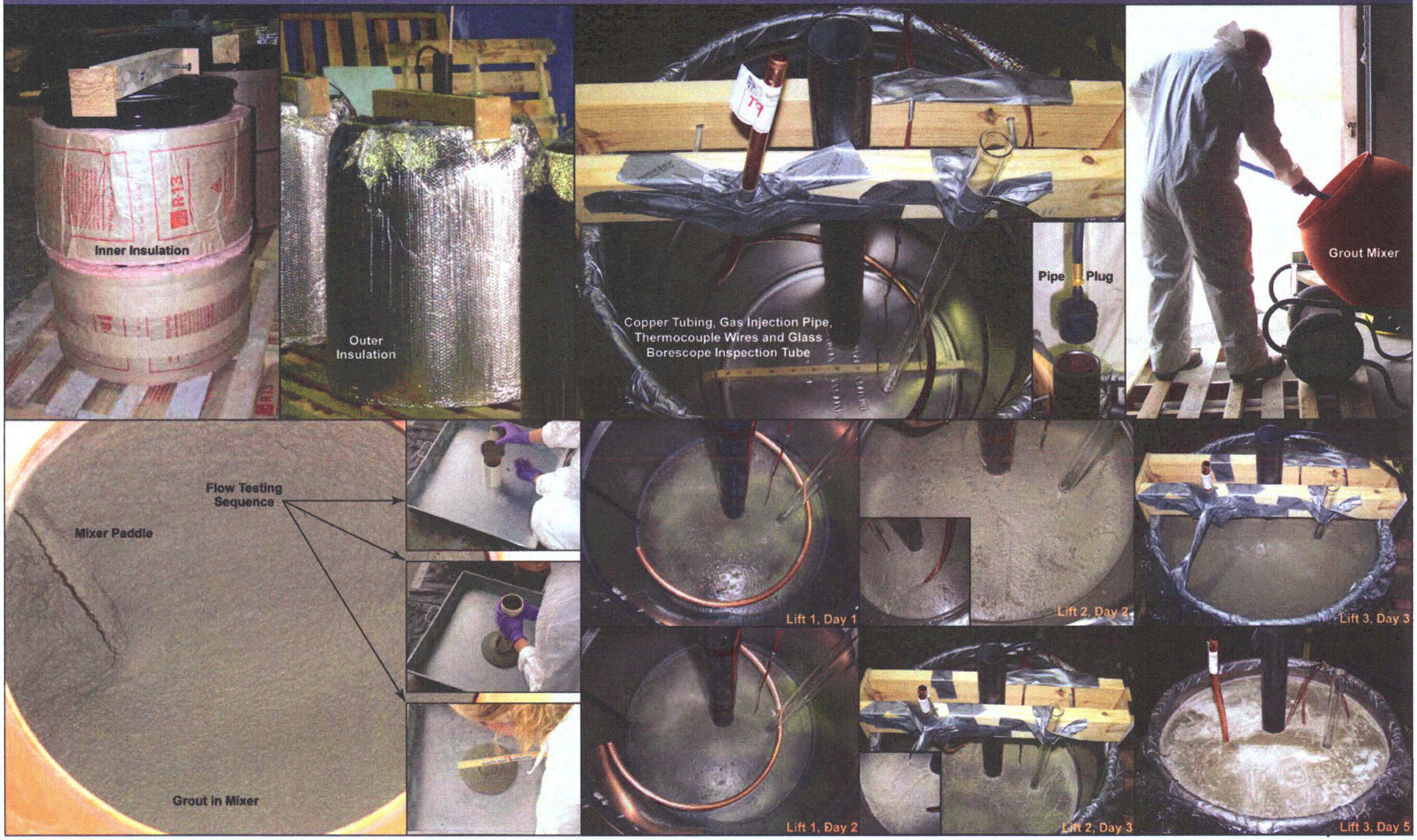
Test Specimen	Grout Formulation			Tank Top Insulated?	Copper Tubing?	Glass Borescope Tubing?	Central Pipe Filled?
	Lift 1	Lift 2	Lift 3				
T1	SRS Strong			✓			
T2	SRS Reducing	SRS Strong		✓			✓
T3	SRS Reducing			✓	✓	✓	✓
T4	SRS Alternative 1			✓	✓		✓
T5	SRS Alternative 2			✓		✓	✓
T6	INL Heel			✓			✓
T7	INL CLSM			✓			
T8	INL Heel	INL CLSM		✓	✓	✓	
T9	SRS Strong				✓	✓	✓
T10	INL CLSM				✓	✓	
T11	SRS Alternative 1				✓	✓	
T12	SRS Alternative 2						

Thermal Expansion & Contraction (55-gallon drum) Specimens

Insulation & Temperature Monitoring



Drum Grout Specimen Prep



INL Heel Grout

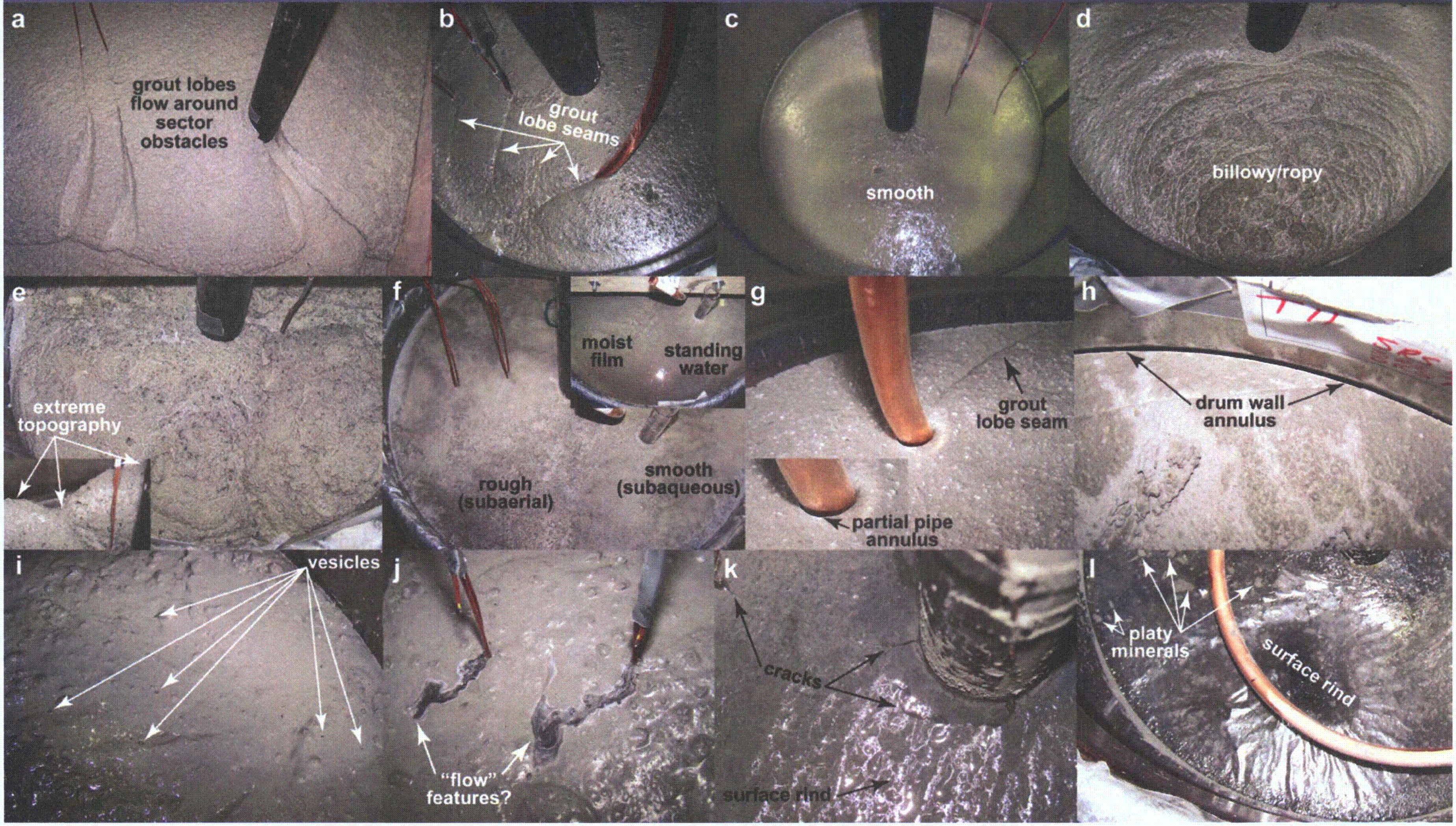
- We found two different DOE formulas for INL Heel Grout
  - Langton and Cook (2008)
  - CH2M WG Idaho, LLC (2007)

  with two different quantities for water and high-range water reducer (HRWR)
- Neither formula produced a grout that would meet the ASTM C-1161 slump flow specification of CH2M WG Idaho, LLC (2007), which called for slump flow of 6 to 11 inches in diameter
- Instead, we used water and HRWR quantities between these limits to meet the desired slump flow; but meeting this specification resulted in a grout that was very thick, lumpy, and permeable

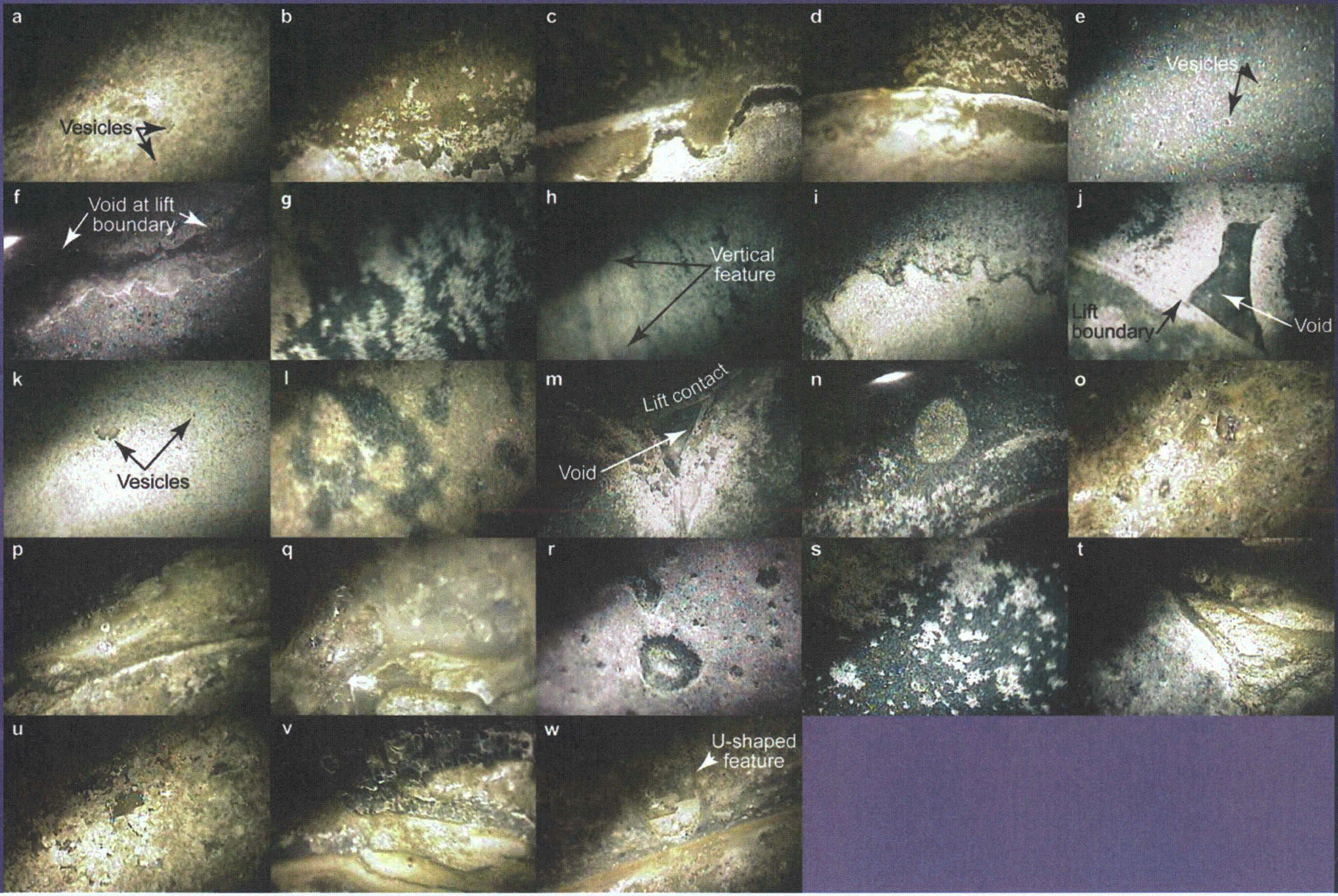
INL CLSM Grout

- Despite concerted efforts to prevent solid-liquid segregation, the formula for INL CLSM Grout (Langton and Cook, 2008) produced a grout prone to segregation
- While in the mixer and during flow testing, this grout never seemed on the verge of segregation as some other formulas had, but when mixing stopped and the grout was poured into a drum or archival sample container, solids and water would immediately segregate, leaving standing water on the surface of each lift
- Unlike INL Heel, INL CLSM produced a very impermeable grout

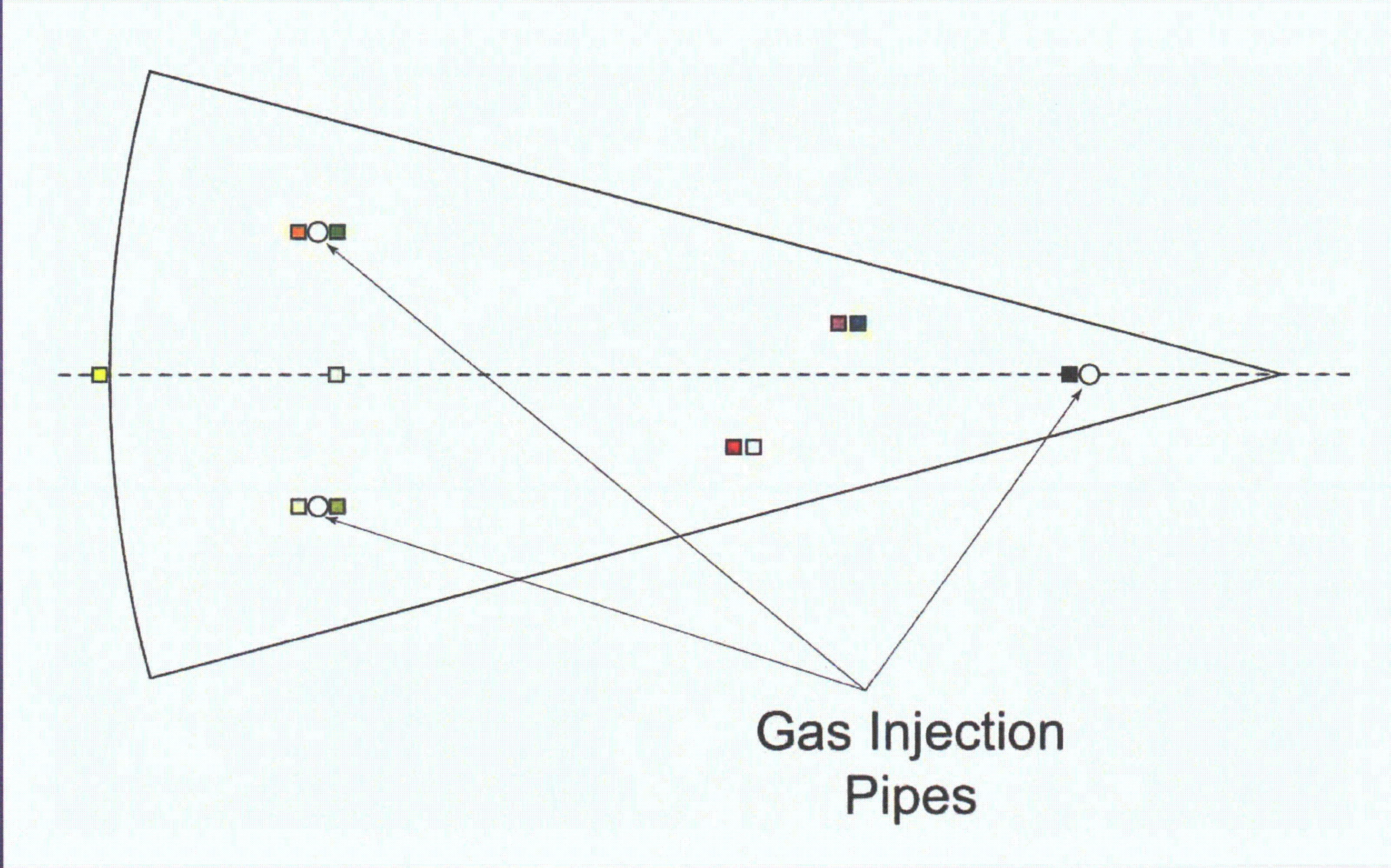
Grout Surface Features



Borescopic Observations

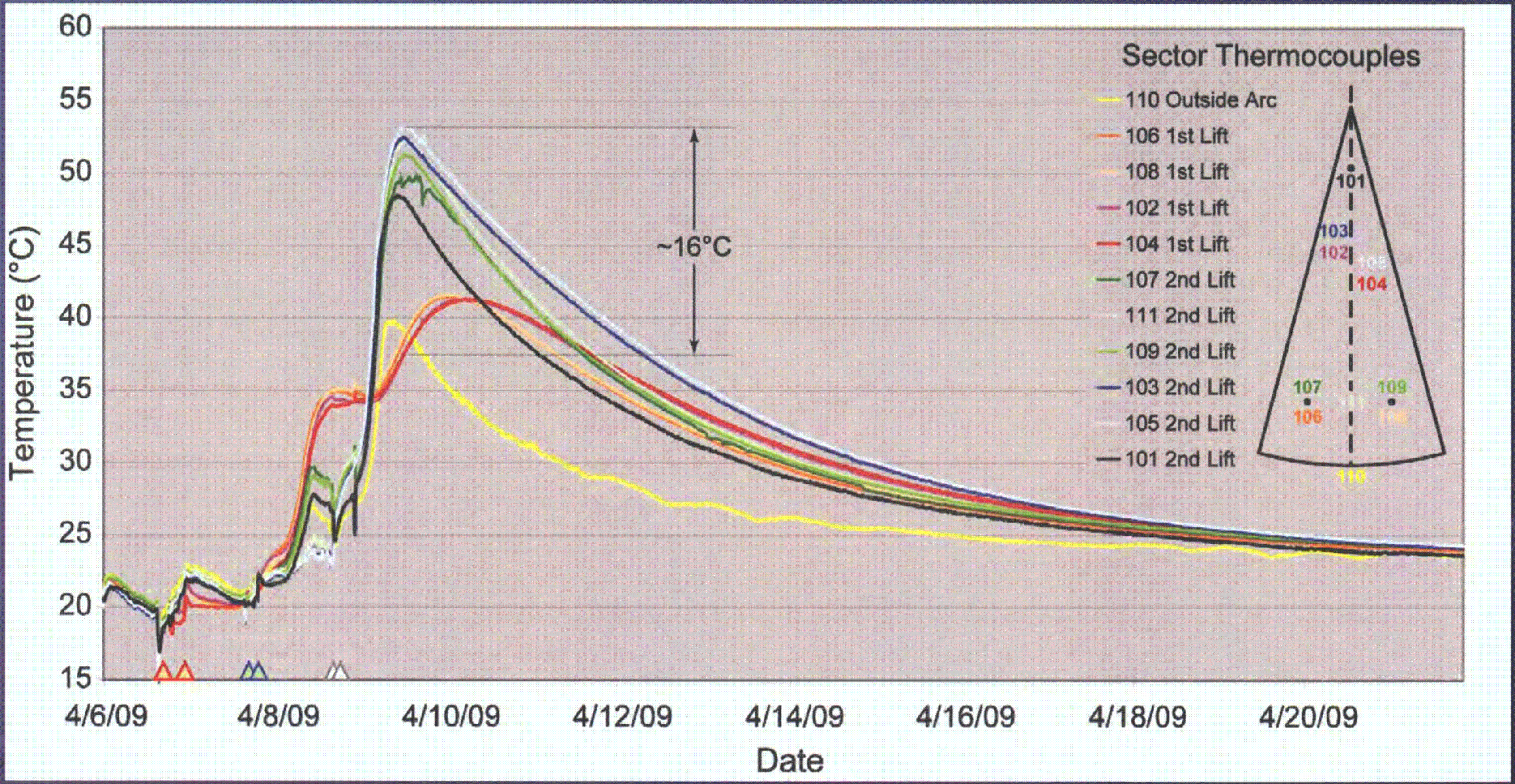


Thermal Hydration and Drying Shrinkage Specimen



Sector Grout Specimen Prep

Thermal Evolution: Sector Specimen



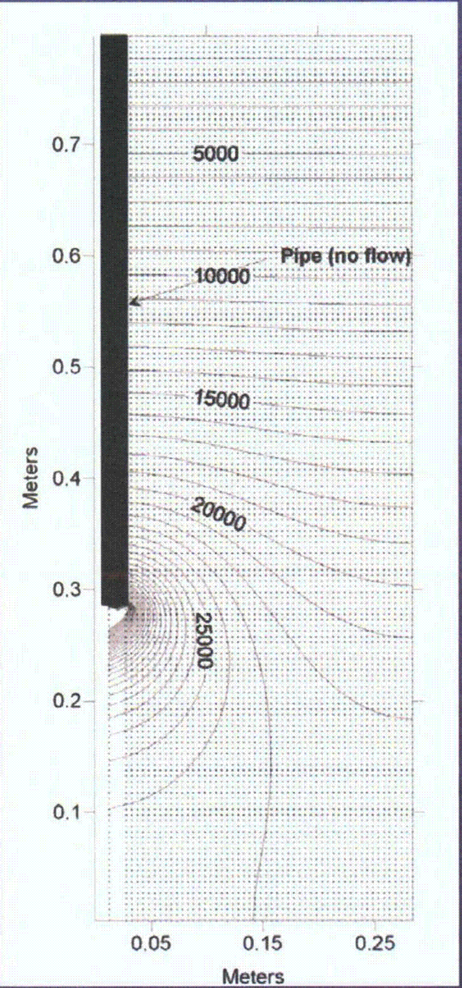
Gas Injection Testing

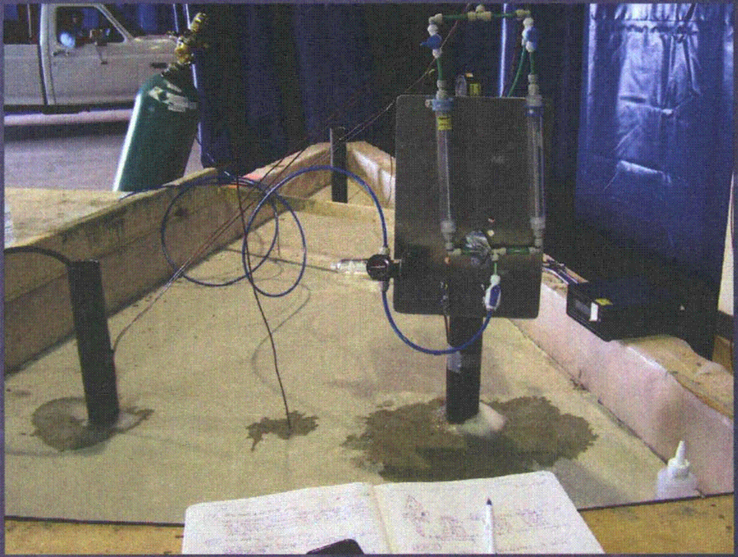
Calculated Average Annular Apertures Between Injection Pipe and Drum or Sector Grout					
Test Specimen	**Grout Formulation**			**Aperture (µm)**	**Flow Behavior**
	Lift 1	**Lift 2**	**Lift 3**		
Drum Grout Specimens					
T1	SRS Strong			8.1	High Velocity Flow Effect
T2	SRS Reducing	SRS Strong		5.1	Borderline Darcy Flow
T3	SRS Reducing			6.8	High Velocity Flow Effect
T4	SRS Alternative 1			7.1	High Velocity Flow Effect
T5	SRS Alternative 2			8.8	High Velocity Flow Effect
T6	INL Heel			"78.0"	Darcy Flow (diffuse + annular between grout and drum wall)
T7	INL CLSM			2.1	Darcy Flow
T8	INL Heel	INL CLSM		1.1	Undetermined
T9	SRS Strong			17.9	High Velocity Flow Effect
T10	INL CLSM			2.7	Darcy Flow
T11	SRS Alternative 1			6.2	High Velocity Flow Effect
T12	SRS Alternative 2			7.3	Darcy Flow
¼-Scale Sector Grout Specimen					
Pipe A	SRS Reducing	SRS Strong		19.7	High Velocity Flow Effect
Pipe B	SRS Reducing	SRS Strong		17.5	High Velocity Flow Effect
Pipe C	SRS Reducing	SRS Strong		13.9	Borderline Darcy Flow

Pipe Grout Gas Injection Testing

Calculated Average Annular Apertures Between INL Pipe Grout and Injection Pipe					
Test Specimen	**Grout Formulation**			**Aperture (µm)**	**Flow Behavior**
	Lift 1	**Lift 2**	**Lift 3**		
Drum Grout Specimens					
T2	SRS Reducing	SRS Strong		3.5	Indeterminate
T3	SRS Reducing			1.5	Indeterminate
T4	SRS Alternative 1			0.0	No Flow
T5	SRS Alternative 2			3.9	Darcy Flow
T6	INL Heel			0.0	No Flow
T9	SRS Strong			2.7	Darcy Flow
¼-Scale Sector Grout Specimen					
Pipe A	SRS Reducing	SRS Strong		4.5	Darcy Flow
Pipe B	SRS Reducing	SRS Strong		0.0	No Flow
Pipe C	SRS Reducing	SRS Strong		4.4	Darcy Flow

Effective Gas Permeability





Calculated Effective Gas Permeabilities for Selected Drum Grouts		
Grout	k_{eg} (m^2)	K_{eg} (cm/s H_2O)
SRS Strong	$9.3 \pm 3.3 \times 10^{-15}$	$6.6 \pm 2.6 \times 10^{-8}$
SRS Reducing/Strong	$2.2 \pm 0.13 \times 10^{-15}$	$1.5 \pm 0.08 \times 10^{-8}$
INL Heel	$1.6 \pm 0.21 \times 10^{-11}$	$1.1 \pm 0.14 \times 10^{-4}$
INL CLSM	$2.6 \pm 0.67 \times 10^{-16}$	$1.8 \pm 0.05 \times 10^{-9}$
INL Heel/CLSM	$1.6 \pm 0.15 \times 10^{-16}$	$1.1 \pm 0.15 \times 10^{-9}$

Conclusions

- We generally achieved the desired grout flowability at a lower water-to-cement ratio than the nominal water in grout formulations would indicate; this could be attributed to differences in the properties of our Portland cement, fly ash, and blastfurnace slag cement relative to those used by DOE
- The variations in water-to-cement ratios between batches suggest careful quality control may be required during full-scale grout emplacement to maintain consistent grout properties
- Little evidence of thermal cracking was visible in grout surfaces; perhaps because the non-scale model nature of our experiments did not attain the maximum temperatures expected for a full-scale NDAA tank

Conclusions

- The most significant finding of this study was that annular gaps developed between pipe walls and grout in nearly all the our mesoscale specimens, including pipe grout specimens
- The approximately 3× larger annular apertures in the sector specimen compared to the drum specimens are attributed to its greater volume and more potential for drying shrinkage
- Flow structures around obstacles, vesicles and vugs within the grout mass, and significant void space at lift separations may all contribute to development of preferential flow pathways as grout ages
- Such permeable pathways may not have been penetrated by the gas injection tests performed, and thus not accounted for in bulk permeability estimates

Recommendations

- Prepare and test
  - Larger grout specimens
  - Specimens subjected to higher temperature regimes
- Elucidate the three-dimensional permeability structure of the grouts by performing dye tracer tests on laboratory- and mesoscale grout samples; these tests would focus on transport through fractured and void-containing grout, and within annuli by observing dye tracer interaction with adjacent grout matrix
- Characterize the solid-phase assemblages in grout samples representing varying conditions and locations to inform evaluation of chemical reactions potentially affecting radionuclide mobility in the grout