About the Presenter

- **Terry Arnold** is the Federal Lab Manager of the Chemistry Research Laboratory at the Federal Highway Administration (FHWA) Turner-Fairbank Highway Research Center (TFHRC) in McLean, VA.
- The Chemistry Research Laboratory is part of the Pavement Materials Team (HRDI-10) and carries out research into both concrete and asphalt-related materials.
- Terry has more than 20 years experience in working with the chemistry of pavement materials.
- Originally from the United Kingdom, Terry is a Chartered Chemist and a Fellow of the Royal Society of Chemistry in the United Kingdom.

Source: FHWA.

Turner-Fairbank Alkali-Silica Reaction (ASR) Aggregate Susceptibility Test

T-FAST

National Concrete Consortium Virtual Meeting
September 1, 2020

TFHRC Chemistry Laboratory

- Terry Arnold
- Jose Munoz
- Chandni Balachandran
- Freweini Zerai
- Anant Shastry
- John Staaf

Generalities

- This research is a work in progress
- Highly and nonreactive aggregates—Easy
- Middle aggregates—Hard; they are more dependent on alkalinity
- We measure **Reactive Index (RI)**, not physical expansion
- Test should expose the aggregate to what it will see in the concrete
- We have a test for coarse aggregates
- We think the test will work for fine aggregates
- We are working on mitigation strategies
- Ultimate goal is a job mix design test

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Is This Test Any Good?

Objections and questions (highlighted in red):

- We welcome them
- We will deal with them as we proceed

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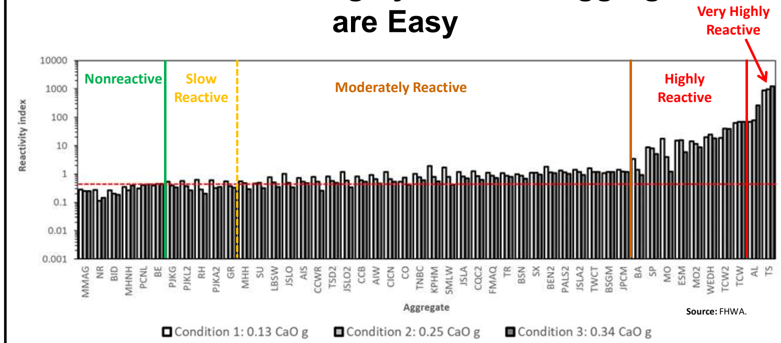
Nonreactive and Highly Reactive Aggregates are Easy



Influence of aggregate mineralogy on the value of RI.

Ca = calcium
g = grams
O = oxygen

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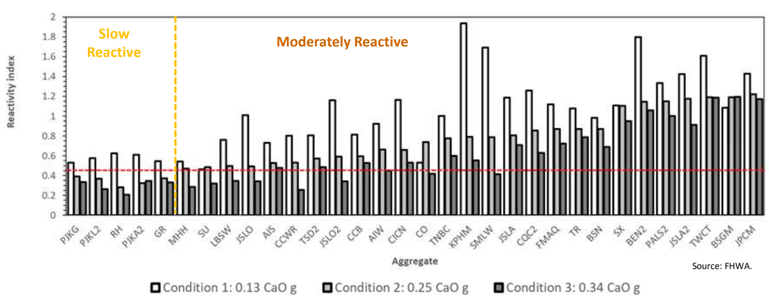
Middle-of-the-Road Aggregates

Aggregate Mineralogy/CaO Content



Influence of alkali content on the value of RI.

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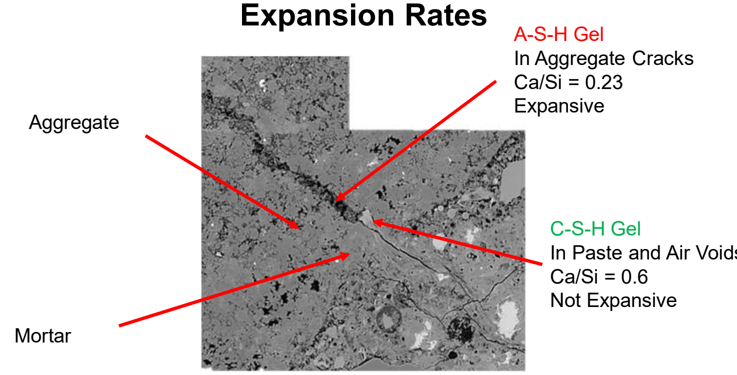
ASR Gels Have Different Compositions and Expansion Rates



Source: FHWA.

Si = silicon

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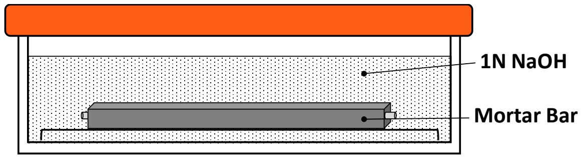
Issues with ASTM C1260* (AASHTO T 303**)



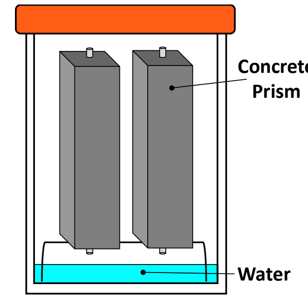
Source: FHWA. Na = sodium

- Unrealistically high alkali level
- 24-hour immersion in water—leaching of calcium
- Low calcium concentration in pore solution favoring formation of expansive A-S-H gel
- Leaching of silicon
- Problems with measuring the physical expansion

American Association of State Highway and Transportation Officials (AASHTO)
*ASTM C1260. *Standard Test Method for Potential Alkali Reactivity of Aggregates (Mortar-Bar Method).* ASTM International, 2014.
**AASHTO T 303. *Standard Method of Test for Accelerated Detection of Potentially Deleterious Expansion of Mortar Bars Due to Alkali–Silica Reaction*. AASHTO, 2000.

Issues with ASTM C1293*

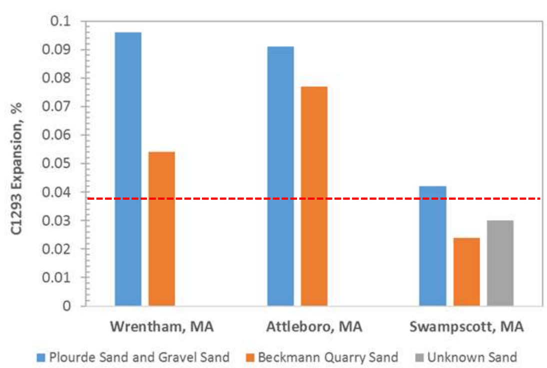
- Almost 40 percent of the initial alkali leaches out of the samples during the first 3 months of the test.
- Problems with leaching silica and calcium
- Problems with measuring the physical expansion



Source: FHWA.

*ASTM C1293. *Standard Test Method for Determination of Length Change of Concrete Due to Alkali-Silica Reaction.* ASTM International, 2020.

Influence of "Nonreactive" Sands



Source: FHWA.

Effect of various "nonreactive" sands on the ASTM C1293 expansion data.

Grieco J. and Willsmer T. (2017). *The prescription for curing concrete (Healing ASR). Innovation & Tech Transfer Exchange*. Massachusetts Department of Transportation (MassDOT). http://www.umasstransportationcenter.org/Document.asp?DocID=236

T-FAST Complicated?

Objection—The T-FAST Test is overly complicated

- ASTM C1260: 15 Steps — Test Duration: 16 Days
- ASTM C1293: 14 Steps — Test Duration: 365 days
- AASHTO T 380*: 22 Steps (Miniature Concrete Prism Test (MCPT)) — Test Duration: 56–84 Days
- T-FAST: 5 Steps — Test Duration: 21 Days

*AASHTO T 380. *Standard Method of Test for Potential Alkali Reactivity of Aggregates and Effectiveness of ASR Mitigation Measures (Miniature Concrete Prism Test, MCPT).* AASHTO, 2019.

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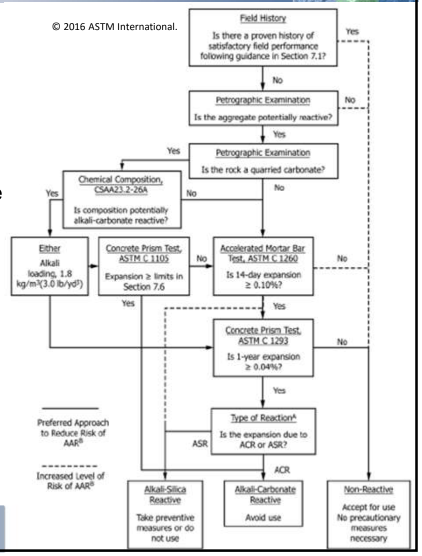
ASTM C1778 – 20*

Standard Guide for Reducing the Risk of Deleterious Alkali-Aggregate Reaction in Concrete



AAR = alkali-aggregate reaction
ACR = alkali-carbonate reaction
kg = kilogram
lb = pound
m = meter
yd = yard

Reprinted with permission from ASTM. ASTM C1778 – 20, *Standard Guide for Reducing the Risk of Deleterious Alkali-Aggregate Reaction in Concrete*, ASTM International, 2020.A copy of the complete standard may be obtained from ASTM International, www.astm.org.

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Characteristics of T-FAST

- Simplified system has all the key players for ASR (pore solution, portlandite, and reactive aggregate).
- Sealed system—leaching is not possible.
- Chemical test does not just measure Si dissolution or alkali consumption or pH.
- Ca and aluminum (Al) contents are linked to gel formation and its composition (linked to expansion).
- Conditions mimic long-term concrete pore solution.

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What is the T-FAST Test?

- 600 g aggregate obtained by ASTM D75* or C702**
- Crush sufficient material to finally end up with sufficient material retained on No. 50 and No. 100 sieves.
- Crusher must not contaminate the sample
- Our crusher has tungsten carbide faces

Source FHWA.

*ASTM D75. *Standard Practice for Sampling Aggregates*. ASTM International, 2019.
**ASTM C702. *Standard Practice for Reducing Samples of Aggregate to Testing Size*. ASTM International, 2018.

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Take 5 g of Crushed Aggregate

Source: FHWA.

µm= microns

Objection: 5 g is too small to be representative. We have excellent reproducibility and agreement with published field data.

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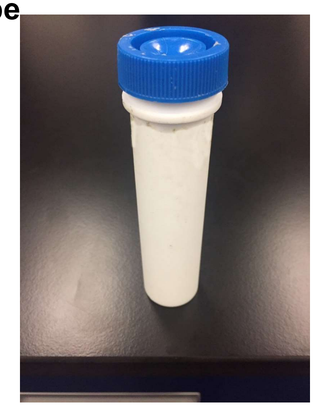
Use a Test Polytetrafluoroethylene (PTFE) Test Tube

- Cannot use glass
- This is a sealed system; there is no possibility of leaching

Objection on Cost:
The tubes are about $50 each; they are reusable



Source FHWA.

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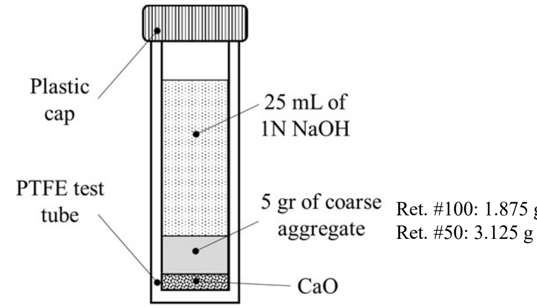
Load the tube



Source: FHWA.

mL = milliliter

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Place the Tube in a 55 ℃ Oven for 21 Days

Objection on Cost:

A standard benchtop oven will hold 200–300 tubes.

There is no need for environmental chambers or rooms.

One technician could prepare 20–30 tubes per day.

Source FHWA.

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Filter the Contents and Analyze the Filtrate

- **We Used Inductively Coupled Plasma (ICP)**
- **We are Looking at X-Ray Fluorescence (XRF)**

Objection on Cost:

ICP costs about $100 thousand

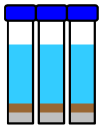
A department of transportation (DOT) sent us a file of ASTM C1260 results

DOTs were paying $1,000 per test

DOTs spent $4.2 million over 10 years

Source FHWA.

Leave the Tube in the Oven for 21 Days



→ Oven 55 °C for 21 days → Vacuum Filtration → ICP Analysis for Si, Ca, Al → $RI = \frac{[Si]}{[Ca] + [}$

Source: FHWA.

Hypothesis:

If RI > **0.45**, ASR expansion
If RI ≤ **0.45**, no ASR expansion

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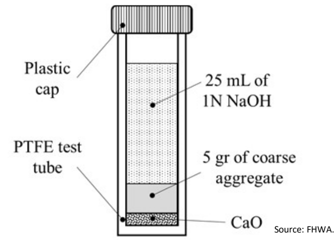
Testing Aggregate the Mix Alkalinity is Unknown



Source: FHWA.

Source: FHWA.

Four testing conditions (three replicas/conditions):

Condition 1: 0.13 g of CaO (0.10 g $Ca(OH)_2$/g anhydrous cement) at 55 °C

Condition 2: 0.25 g of CaO (0.17 g $Ca(OH)_2$/g anhydrous cement) at 55 °C

Condition 3: 0.34 g of CaO (0.23 g $Ca(OH)_2$/g anhydrous cement) at 55 °C

Condition 4: 0.25 g of CaO (0.17 g $Ca(OH)_2$/g anhydrous cement) at 80 °C

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Turner-Fairbank ASR Susceptibility Test

ASR Classification Criteria

1. If [Si] measured in condition 4 (80 °C) ≤ 1 millimolar (mm) → nonreactive.
2. If [Si] measured in condition 4 (80 °C) > 1 mm → calculate RI for all the conditions and follow classification in the table.

$$RI = \frac{[Si]}{[Ca]+[A}$$

Table. Proposed Criteria for Characterizing Aggregate Reactivity.

Condition 1: 0.13 g CaO at 55 °C	Condition 2: 0.25 g CaO at 55 °C	Condition 3: 0.34 g CaO at 55 °C	Condition 4: 0.25 g CaO at 80 °C	Description of Aggregate Reactivity
RI ≤ 0.45 for three cases			RI ≤ 2	Nonreactive
0.45 < RI ≤ 2 for one case			2 < RI ≤ 100	Slow reactive
0.45 < RI ≤ 2 for at least two cases			2 < RI ≤ 100	Moderately reactive
RI > 2 for at least one case			100 < RI ≤ 1000	Highly reactive
RI > 2 for at least one case			RI > 1000	Very highly reactive

Source: FHWA.

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TFHRC ASR Susceptibility Test

Proposed Criteria for Characterizing Aggregate Reactivity

Condition 1: 0.13 g CaO at 55 °C	Condition 2: 0.25 g CaO at 55 °C	Condition 3: 0.34 g CaO at 55 °C	Condition 4: 0.25 g CaO at 80 °C	Description of Aggregate Reactivity
RI ≤ 0.45 for three cases			RI ≤ 2	Nonreactive
0.45 < RI ≤ 2 for one case			2 < RI ≤ 100	Slow reactive
0.45 < RI ≤ 2 for at least two cases			2 < RI ≤ 100	Moderately reactive
RI > 2 for at least one case			100 < RI ≤ 1000	Highly reactive
RI > 2 for at least one case			RI > 1000	Very highly reactive

Source: FHWA.

Examples:

Aggregate Source	[Si], mm Condition 4	RI Condition 1	RI Condition 2	RI Condition 3	RI Condition 4	Description of Aggregate Reactivity
Quarried Limestone, IL	0.25	N/A	N/A	N/A	N/A	Nonreactive
Beckmann Quarry, TX	1.01	0.40	0.44	0.44	0.35	Nonreactive
Acushnet MA	22.24	0.61	0.32	0.34	8.09	Slow reactive
Wrentham, MA	47.44	0.92	0.66	0.47	29.20	Moderately reactive
Bardon Trimount, MA	409	3.38	1.43	0.93	229.92	Highly reactive
Henniker, NH	36.05	0.35	0.27	0.40	6.79	Non/Slow reactive
Middlebury, MA	203.87	1.43	1.22	1.17	103.03	Moderately/Highly reactive

Source: FHWA.

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Does T-FAST Work?

Comparison of the reactivity of well-known aggregates

Aggregate Source	Field Performance	ASTM C1260	ASTM C1293	TFHRC ASR Test
Rhyolite – Albuquerque, NM	Highly reactive	Very highly reactive	Very highly reactive	Highly reactive
Greywacke – Moscow, PA	Highly reactive	Highly reactive	Highly reactive	Highly reactive
Mixed gneiss/schist/quartzite – Attleboro, MA	Reactive	Very highly reactive	Moderately reactive	Highly reactive
Siliceous Limestone – Ontario, Canada	Reactive	Highly reactive	Highly reactive	Highly reactive
Greywacke/sandstone – Taunton, MA	Reactive	Very highly reactive	Very highly reactive	Highly reactive
Quarried quartzite – Dell Rapids, SD	Slow reactive	Moderately reactive	Moderately reactive	Moderately reactive
Quarried granite/granite gneiss – Charlottesville, VA	Slow reactive	Nonreactive	Moderately reactive	Slow reactive
Quarried metabasalt and greenstone – Shadwell, VA	Slow reactive	Nonreactive	Moderately reactive	Slow reactive
Mixed gneiss/granitic – Londonderry, NH	Slow reactive	Moderately reactive	Highly reactive	Moderately reactive
Siliceous gravel – Ontario, Canada	Slow reactive	Moderately reactive	Highly reactive	Moderately reactive
Limestone – San Antonio, TX	Nonreactive	-	-	Nonreactive
Diabase (dolerite) – Chantilly, VA	Nonreactive	-	-	Nonreactive
Mixed carbonate and siliceous – Chicago, IL	Nonreactive	-	-	Nonreactive
Dolomite – Chicago, IL	Nonreactive	-	-	Nonreactive

- = blank

Source: FHWA.

References: Hooton 1995, Folliard et al. 2006, Rangaraju et al. 2007, Ideker et al. 2012, Latifee and Rangaraju 2014, Golmakani and Hooton 2016, Grieco and Willsmer 2017

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Does T-FAST Work?

Comparison of the reactivity of 2018 MassDOT aggregates

Aggregate ID	ASTM C1260	ASTM C1293	AASHTO T380	TFHRC ASR Test
PJKA2	Nonreactive	Moderately reactive	Moderately reactive	Slow reactive
AIW	Nonreactive/ Moderately reactive	Moderately reactive	-	Moderately reactive
BEN2	Nonreactive	-	Moderately reactive	Moderately reactive
MO2	Highly reactive	Moderately reactive	Moderately reactive	Highly reactive
BSN	Moderately reactive	-	Moderately reactive	Moderately reactive
AIS	Nonreactive	Nonreactive/ Moderately reactive	Moderately reactive	Moderately reactive
BID	Nonreactive	-	Moderately reactive	Nonreactive/ Slow reactive
CCB	Moderately reactive	-	Nonreactive	Moderately reactive
PALS	Moderately reactive	-	Moderately reactive	Moderately reactive/ Highly Reactive
JPCM	Moderately reactive	-	Moderately reactive	Moderately reactive/ Highly Reactive
JSLA2	Nonreactive	-	Moderately reactive	Moderately reactive
CCWR	Nonreactive	-	Moderately reactive	Moderately reactive
BSGM	Moderately reactive	-	Moderately reactive	Moderately reactive
PJKL2	Nonreactive/ Moderately reactive	-	Nonreactive	Nonreactive/ Slow reactive

- = blank

Source: FHWA.

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Does T-FAST Work?

Comparison of the reactivity of 2019 MassDOT aggregates

Aggregate ID	ASTM C1260	ASTM C1293	AASHTO T 380	TFHRC ASR Test
TCW	-	-	Moderately reactive	Moderately reactive/ Highly Reactive
CQC	-	-	Moderately reactive	Moderately reactive
JSLO	Moderately reactive	-	Moderately reactive	Moderately reactive
JSLA	Nonreactive	-	Moderately reactive	Moderately reactive
PALS	Moderately reactive	-	Moderately reactive	Moderately reactive
PJKL	Nonreactive/ Moderately reactive	-	Nonreactive	Moderately reactive
BEN	Nonreactive	-	Moderately reactive	Slow reactive
FL	-	-	Nonreactive	Slow reactive
HHW	Nonreactive	-	Moderately reactive	Nonreactive/ Slow reactive
TWC	Moderately reactive	-	-	Moderately reactive
PJKA	Nonreactive	Moderately reactive	Moderately reactive	Nonreactive/ Slow reactive

- = blank

Source: FHWA.

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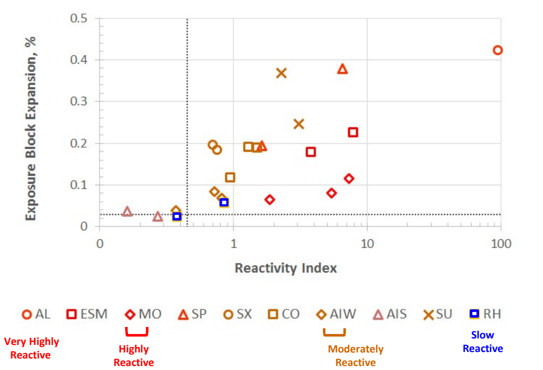
Evaluate ASR Reactivity of Job Mix Designs

Correlation between Exposure Block Expansion Data and TFHRC ASR Test



Source: FHWA.

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Does T-FAST Work?

Comparison of Agreement Between Accelerated Tests and Block Expansion

	Block Farm
ASTM C1260	68%
ASTM C1293	71%
AASHTO T 380	75%
T-FAST	88%
T-FAST (Sand Effect)	100%

Source: FHWA.

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T-FAST and Job Mix Design

- Ultimate goal is a test for job mix designs
- Here we know the alkalinity from the cement mill report
- We have the exact mix design
- We only need to run one tube
- A duplicate is always good laboratory practice
- One technician could prepare 20–30 mixes per day
- We are working on mitigation strategies

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Cooperation

- Expand the calibration of the test; looking for coarse (600 g) and fine (200 g) aggregate samples with:
  - Previous accelerated ASR expansion data (ASTM C1260, ASTM C1293, and AASHTO T 308).
  - Block farm expansion data.
  - Field cases.
- MassDOT, Pennsylvania DOT, California DOT (Caltrans), and the Federal Aviation Administration (FAA) are already cooperating.
- Georgia DOT and Florida DOT expressed interest.

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Cooperation

- For outside groups interested in running T-FAST:
  - We provide:
    - Detailed protocol.
    - Five aggregates with well-known reactivities.
  - Analytical equipment used:
    - Inductively Coupled Plasma (ICP) emission spectrometer.
    - X-ray fluorescence (XRF) spectrometer.
    - Atomic absorption (AA) spectrometer.
- North Carolina DOT (XRF) and Caltrans (ICP).

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Thanks for your attention!

Questions?