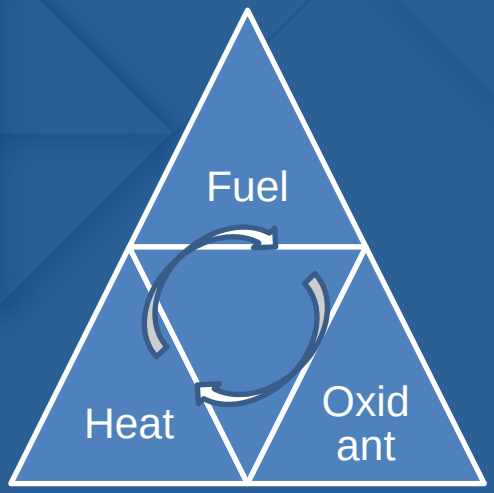
Pilot Test of In-Situ Smoldering Combustion for Remediation of Navy Special Fuel Oil LNAPL



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Project Team

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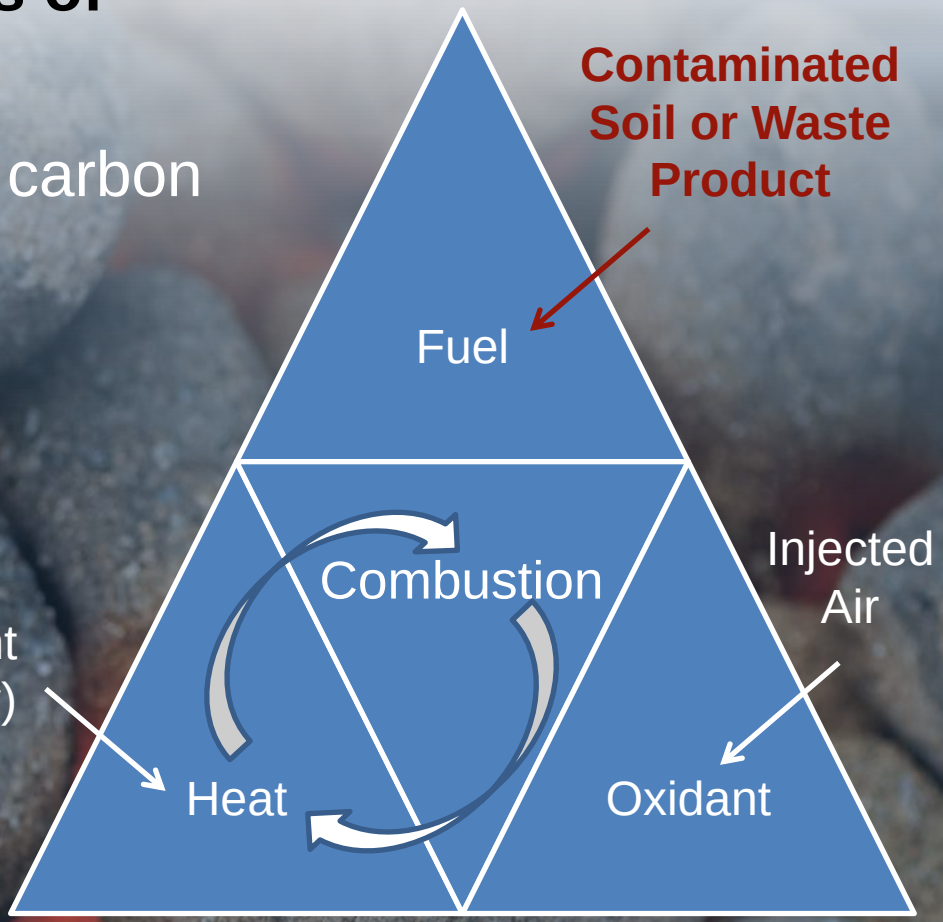
Smoldering Combustion

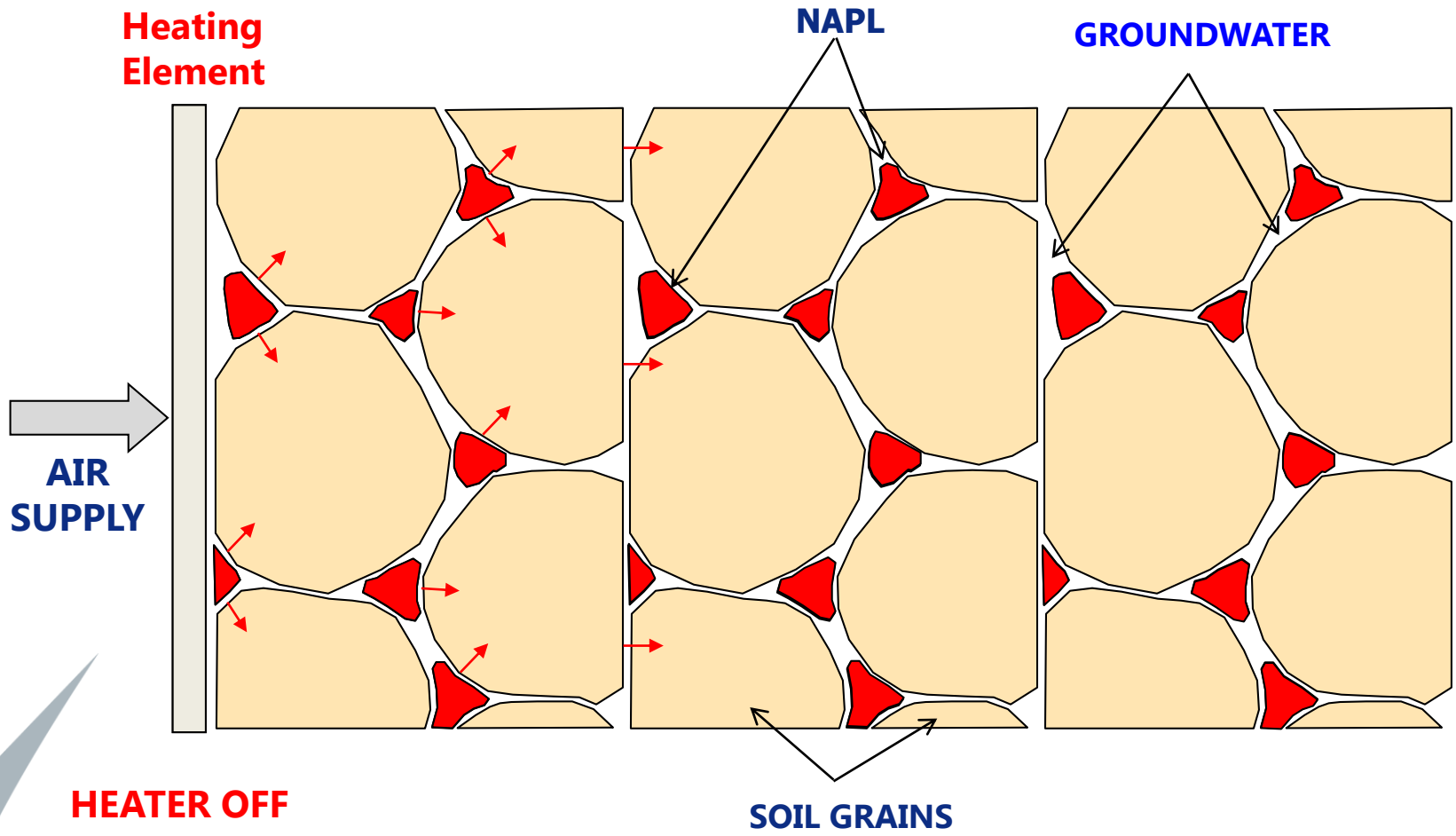
STAR is based on the process of smoldering combustion:

Exothermic reaction converting carbon compounds to $CO_2 + H_2O$



Smoldering possible due to large surface area of organic liquids (e.g., NAPL) within the presence of a porous matrix (e.g., aquifer)

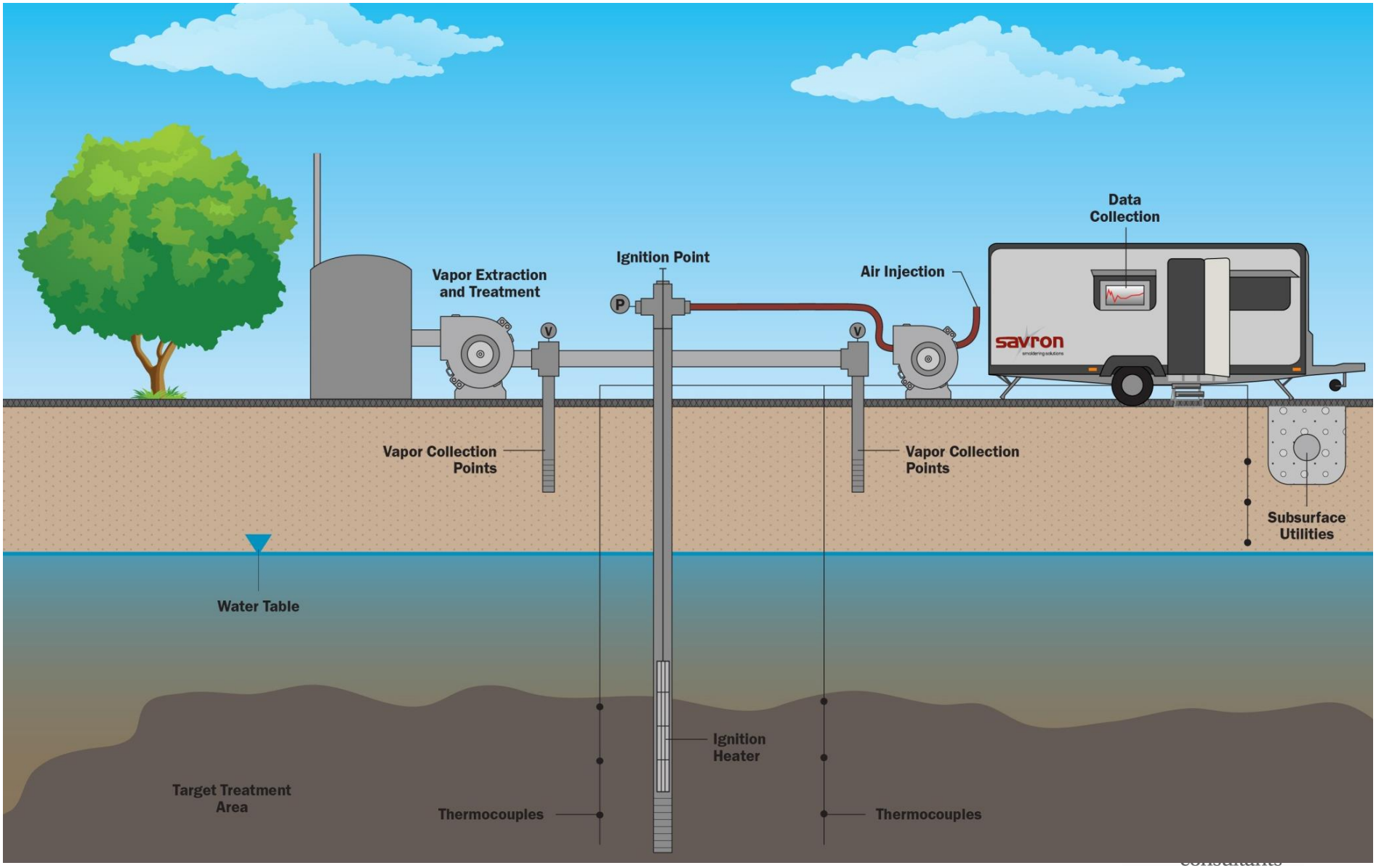
NAPL Smoldering



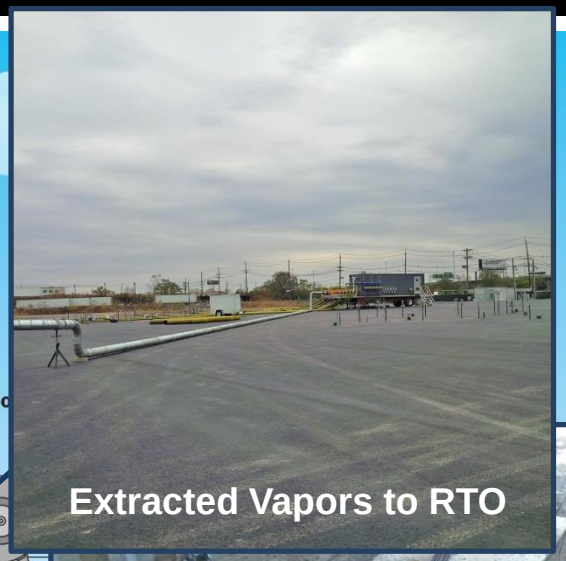
Self-sustaining Treatment for Active Remediation

Video accelerated 50 times

Full-scale System



Full-scale System



Injectio

Vapor Collection Points

Vapor Co Points

Water Table

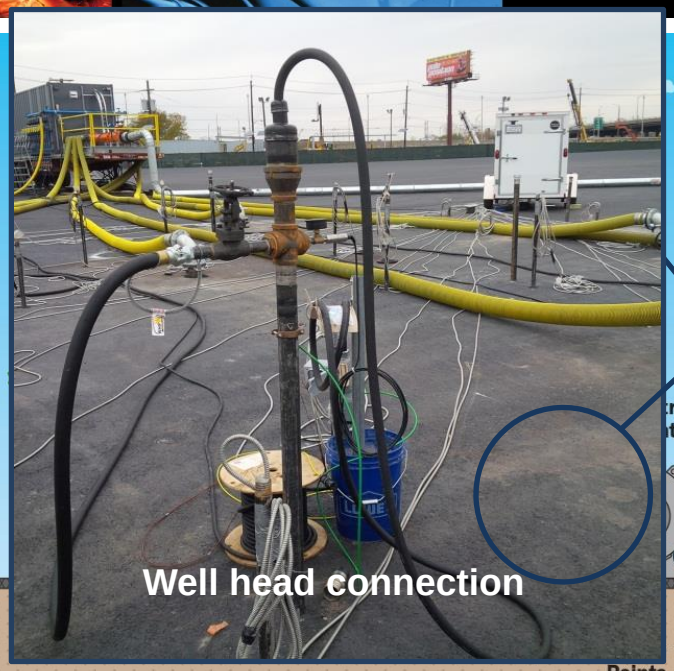
Ignition Heater

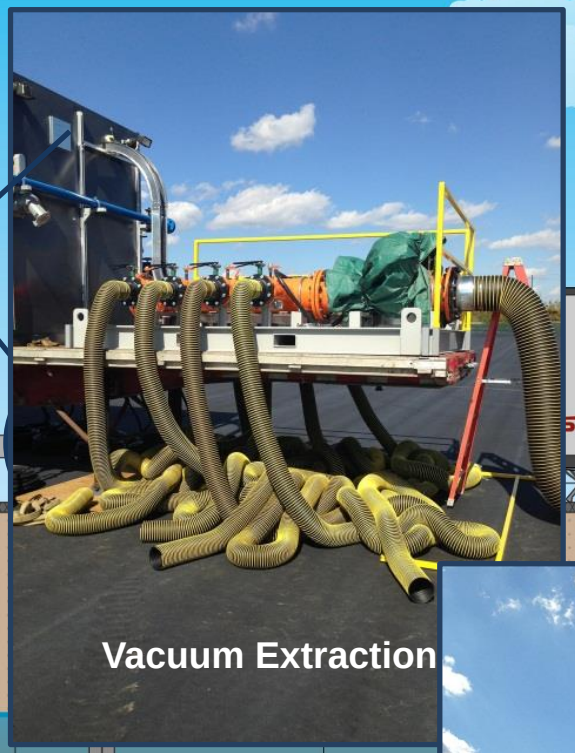
Target Treatment Area

Thermocouples

Thermocouples

Full-scale System





Data Collection

Points

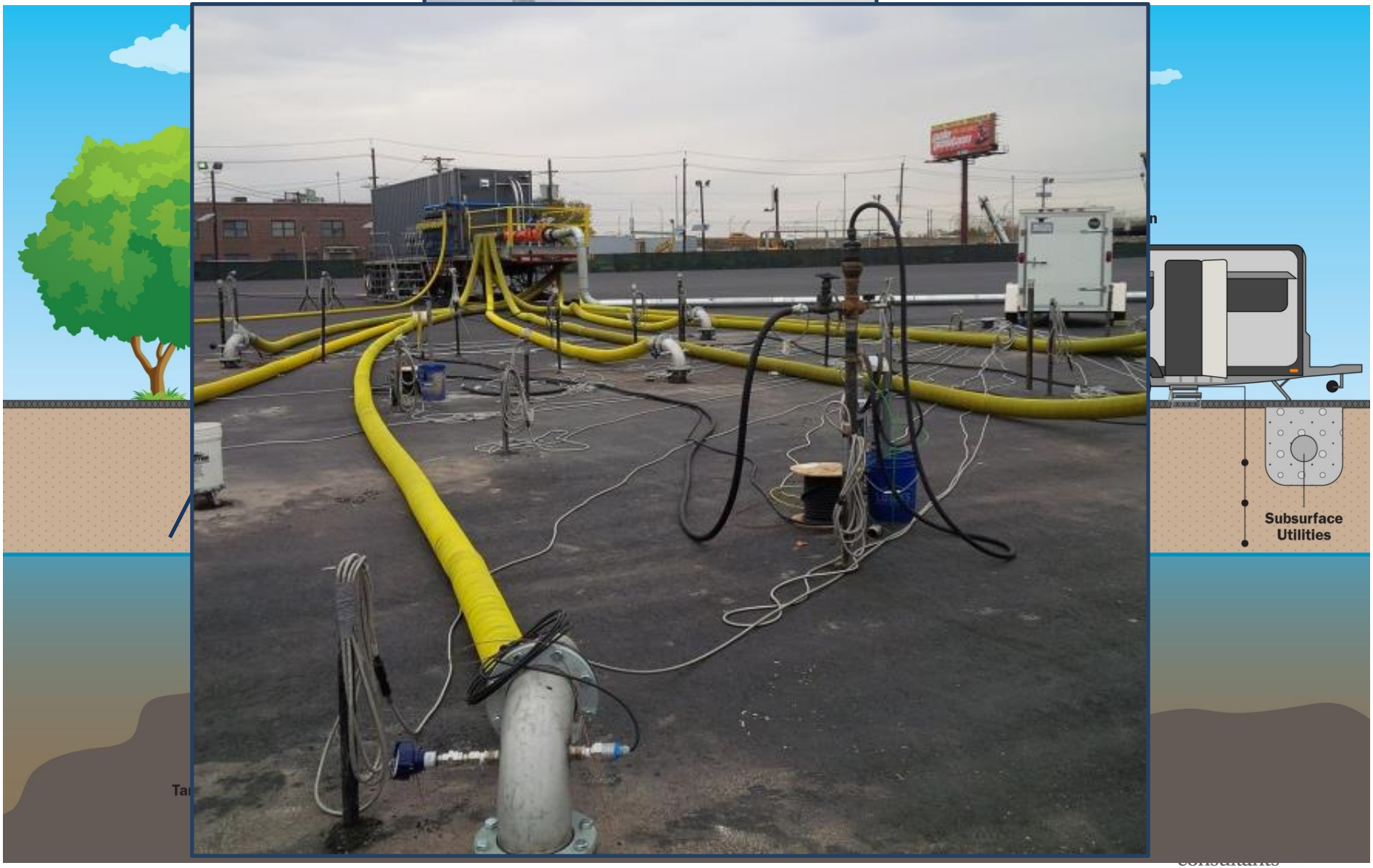
Water Table

Ignition Heater

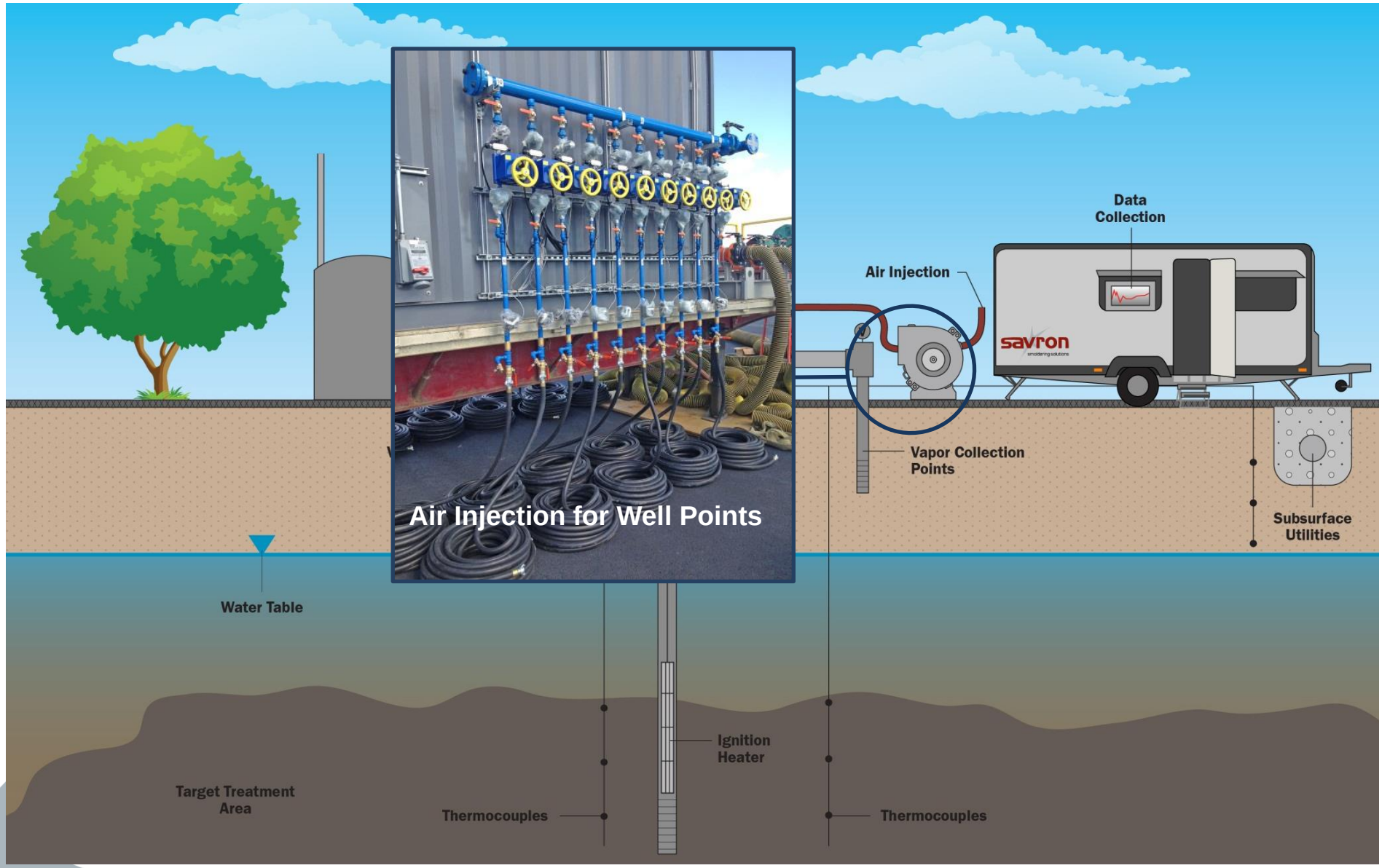
Target Treatment Area

Thermocouples

Full-scale System

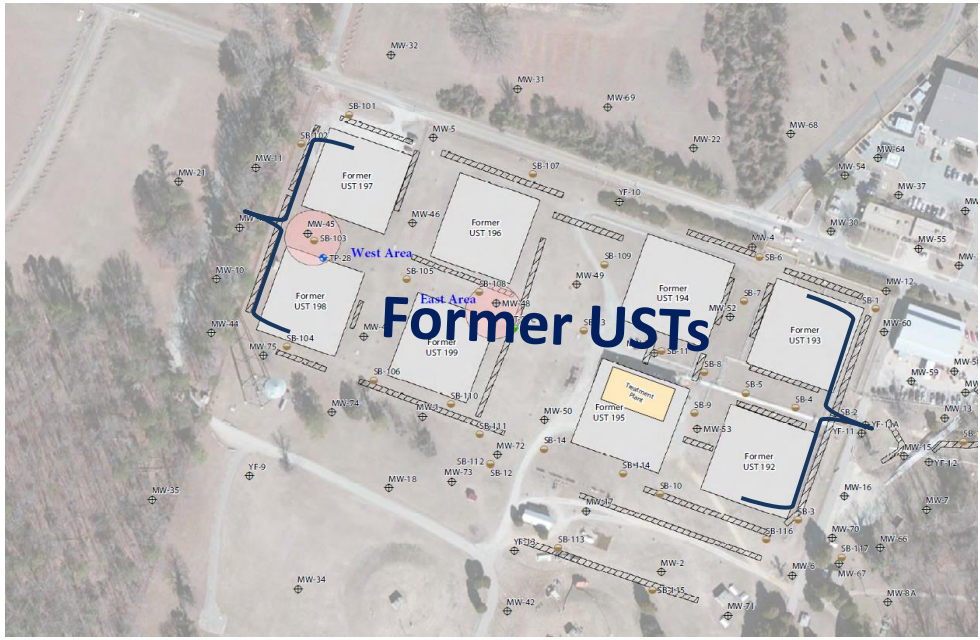


Full-scale System



Navy Fuel Supply Depot

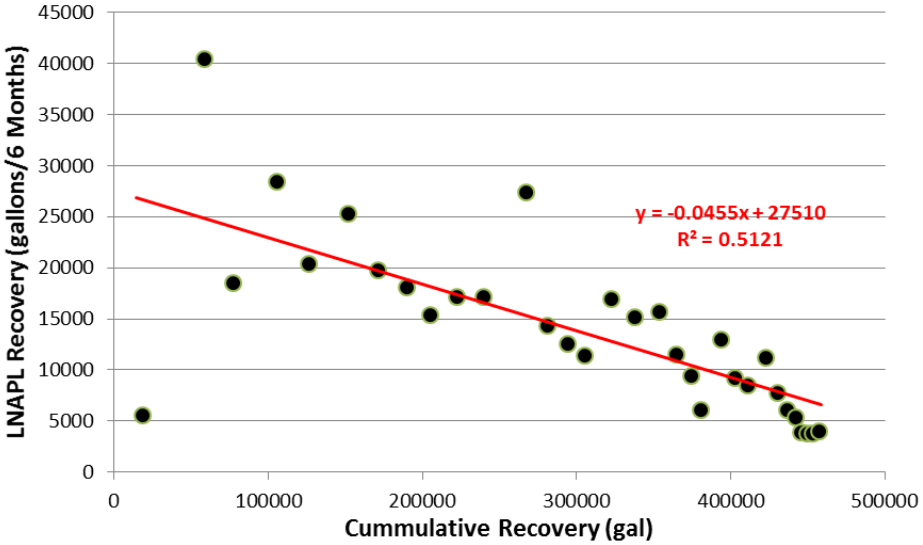
- **~ 110 acres facility**
- **1918 – 1972 Navy Special Fuel Oil (NSFO) in USTs**
- **> 1.2 million gallons mobile LNAPL**
- **LNAPL plume of ~ 13 acres**
- **NSFO – relatively dense and very viscous**
  - Specific gravity : 0.94 to 0.99
  - Viscosity : ~ 500 centistokes (at 59ºF)
- **Medium- to fine-grained sand with varying silt and clay deposits**
- **NSFO contamination ~ 16–21 ft bgs**
- **Clay layer ~ 18–19 ft bgs**



Navy Fuel Supply Depot

Steam-enhanced recovery system

- a closed-loop underground steam grid network (avg. 20 ft bgs);
- a gas-fired boiler for steam generation
- Infiltration of treated & heated (~ 140°F) groundwater



~ 450,000 gal recovered since 2001;

Max. theoretical recovery ~ 605,000 gal;

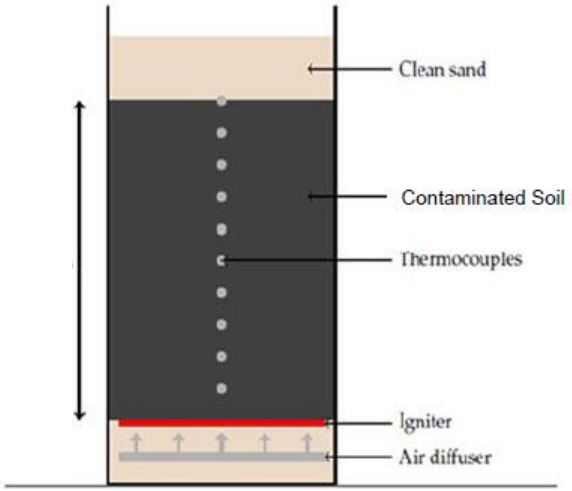
~ $1M annual O&M;

Relatively high energy consumption

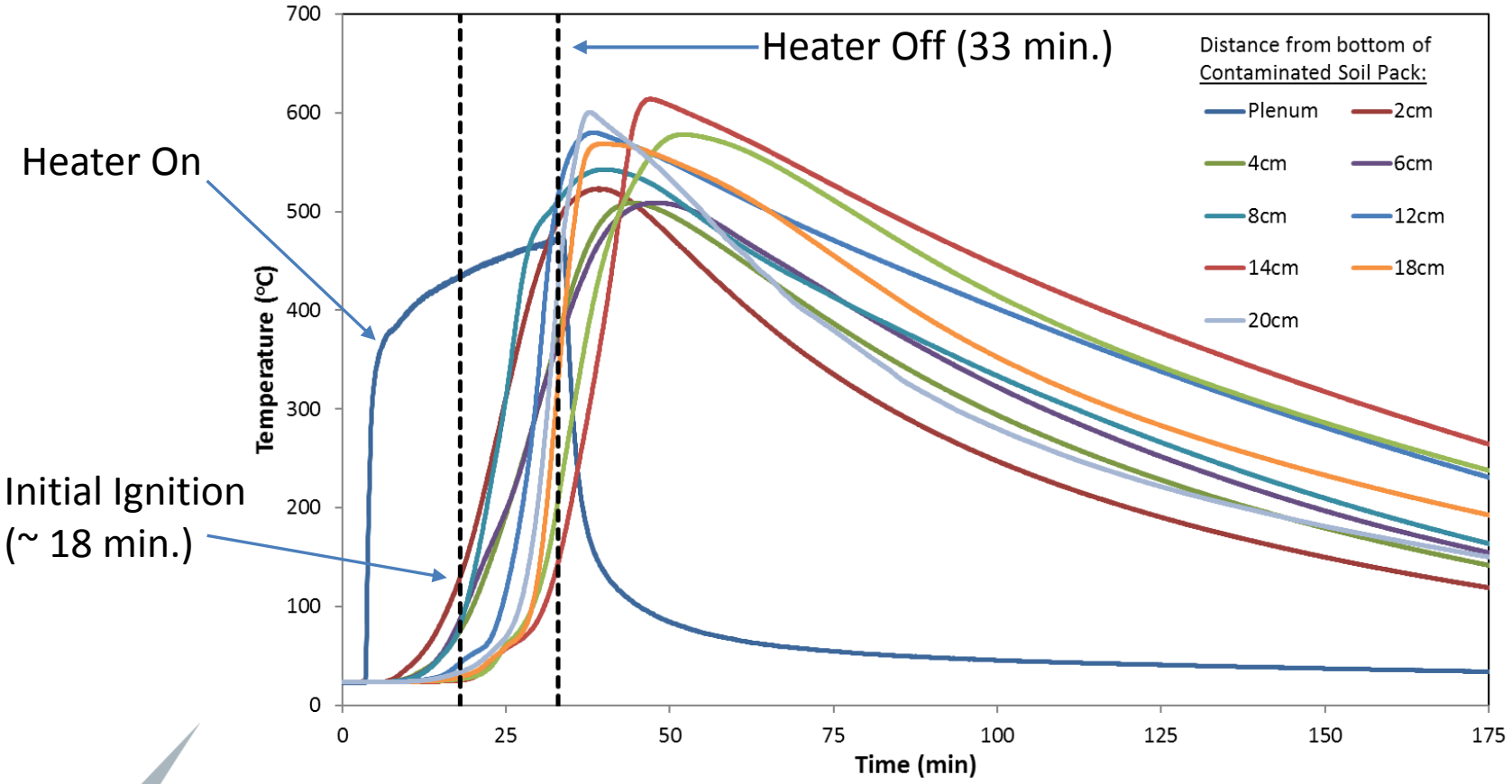
RAOs achievable ?

Bench-Scale Treatability Tests

- Test Vessel Height (Volume): 26 cm (5,225 cm^3)
- Airflow: 60 L/min (5.0 cm/s)
- Heater temperature: 435 °C
- Monitor gas emission



Treatability Test – Temperature Profiles



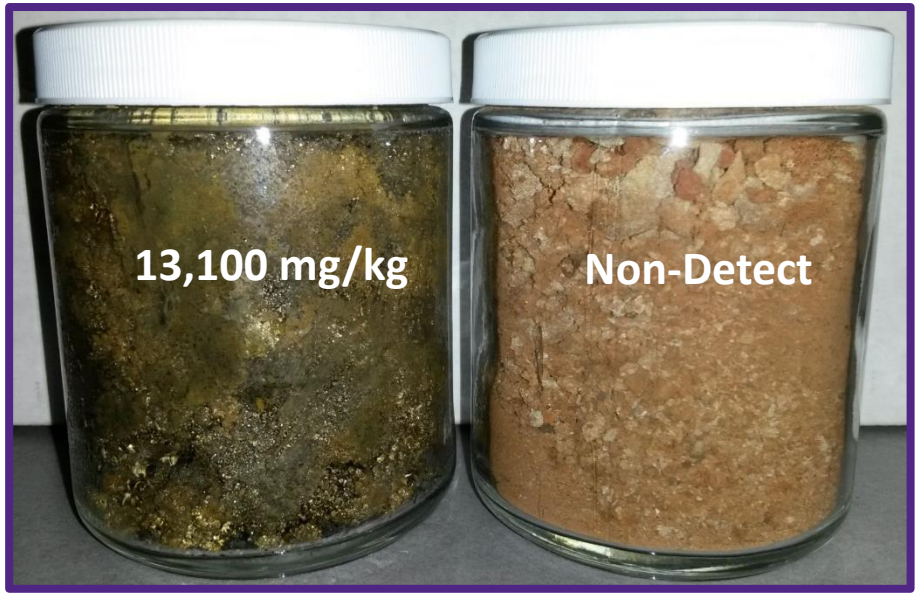
- Peak Temperature: 614°C
- Average Peak Temperature of Combustion: 542°C (Heater temperature: 435 °C)

Treatability Test – Soil Treatment

Soil TPH reduction from 13,100 mg/kg (pre-test) to non-detect (post-test)

The average concentrations of CO and CO_2 were 0.02% and 0.6%, respectively

VOCs in emitted gas generally < 1 ppmv



Can you guess Pre-Treatment Soil vs. Post-Treatment Soil ?

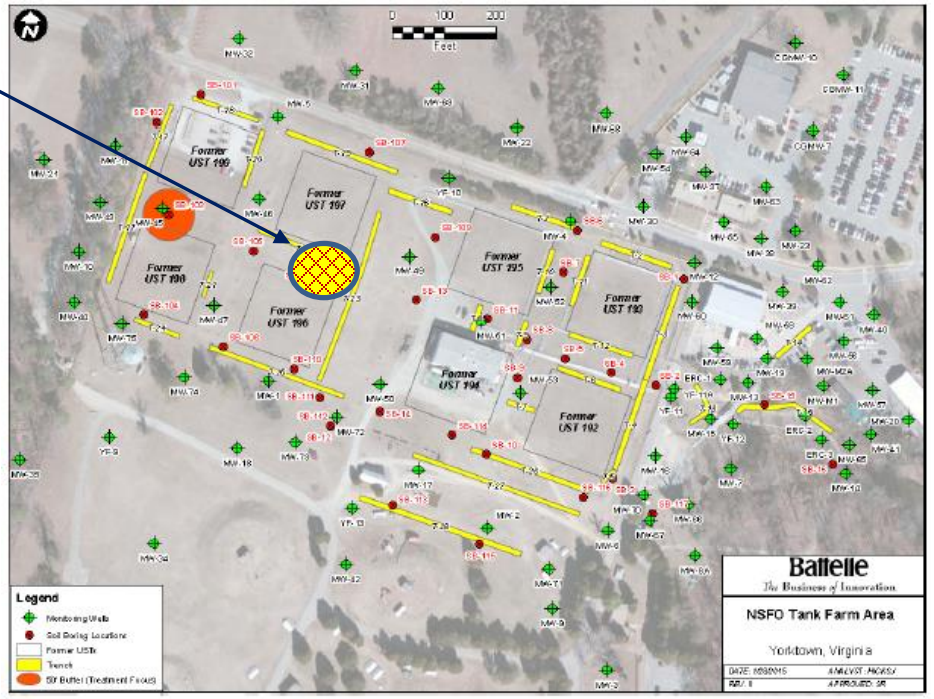
STAR Pilot-Scale Test

Perform a pilot test to

1. Evaluate efficacy of STAR

2. Develop design parameters

- Ignition and peak temperatures
- Air flow rates
- Combustion front propagation
- Treatment zone achievable (aerial extent and vertical interval)
- Mass reduction



Pilot Test – Approach / Design

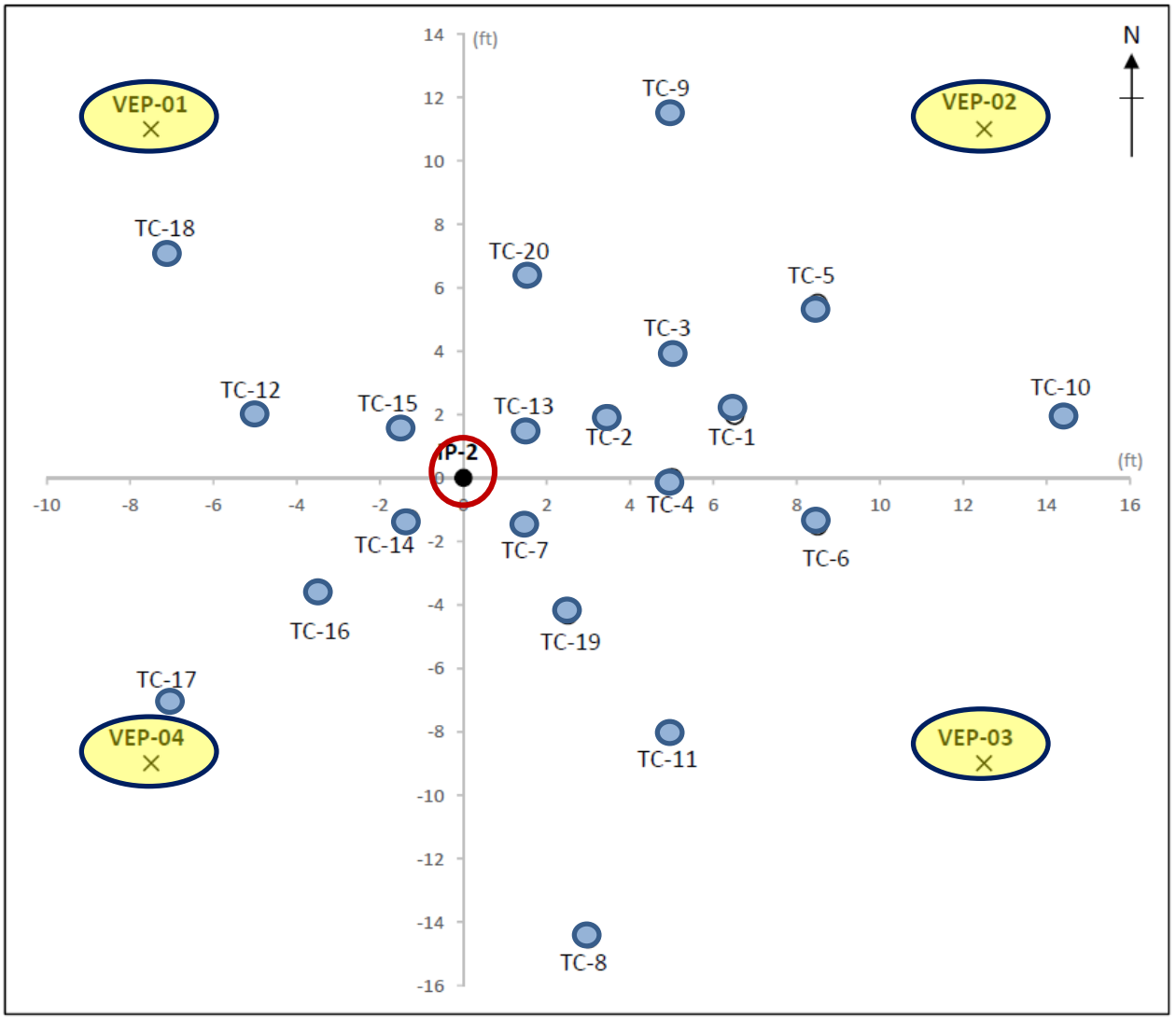
Pilot test area of ~ 30 ft by 30 ft

Water table at ~ 16-18 ft bgs

IP screened at 20-21 ft bgs, which was below clay at ~ 18-19 ft bgs

Four VEPs screened 4–14 ft bgs

A network of multi-level thermocouples



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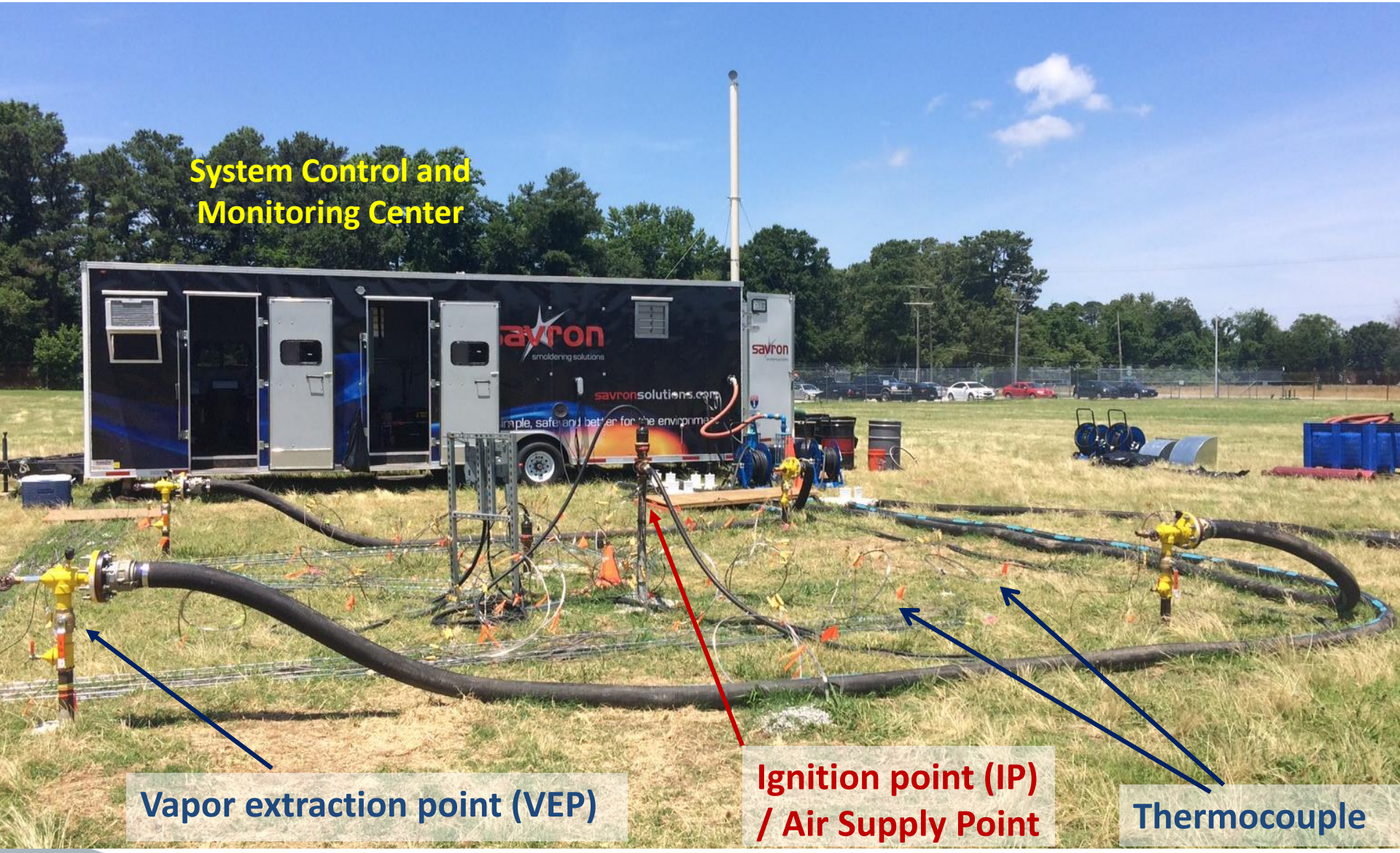
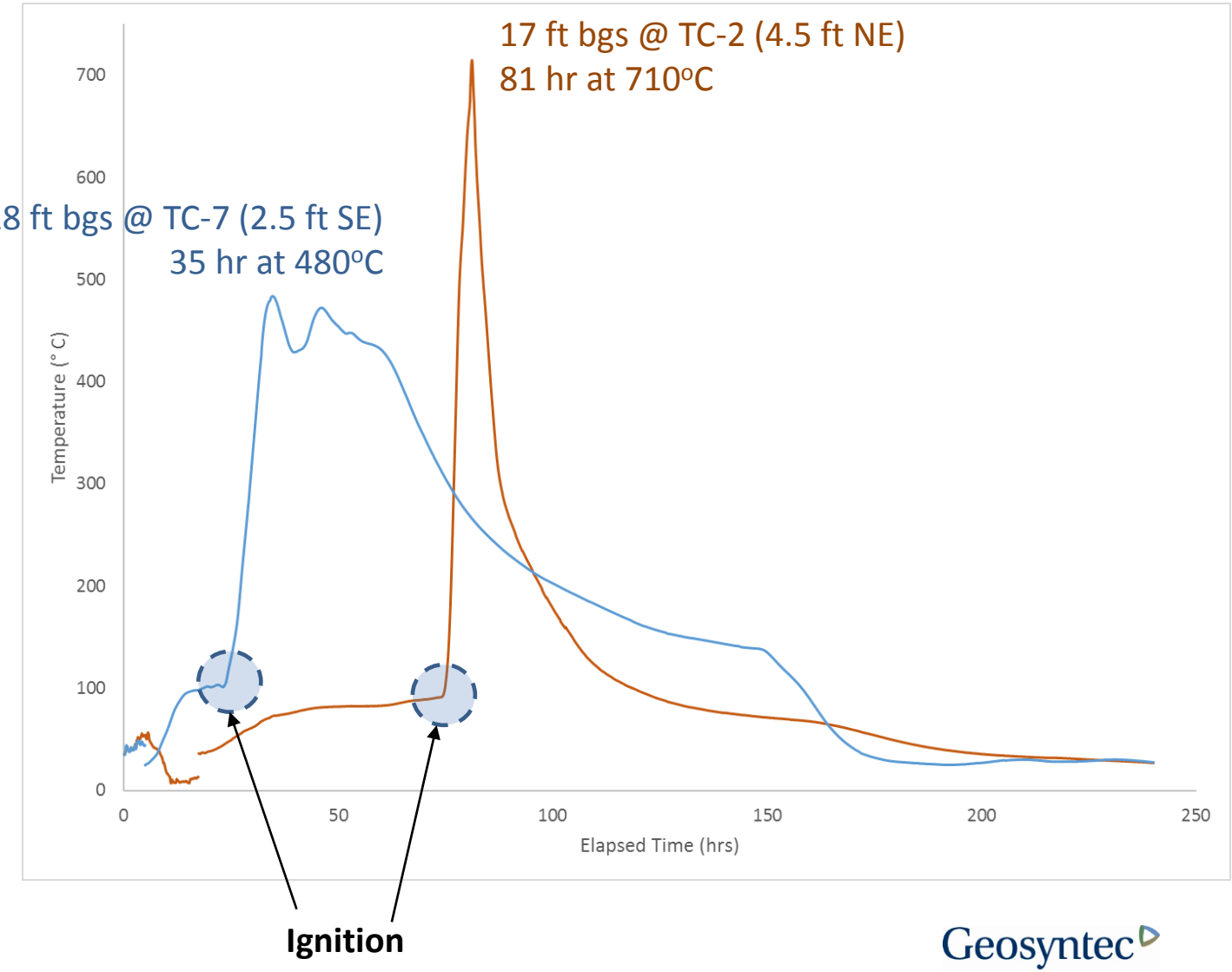
Pilot Test – Field System & Setup



Pilot Test Results – Temperature Profiles

In general, overall readings from the thermocouple network were inconclusive

Select thermocouples exhibited ignition signatures



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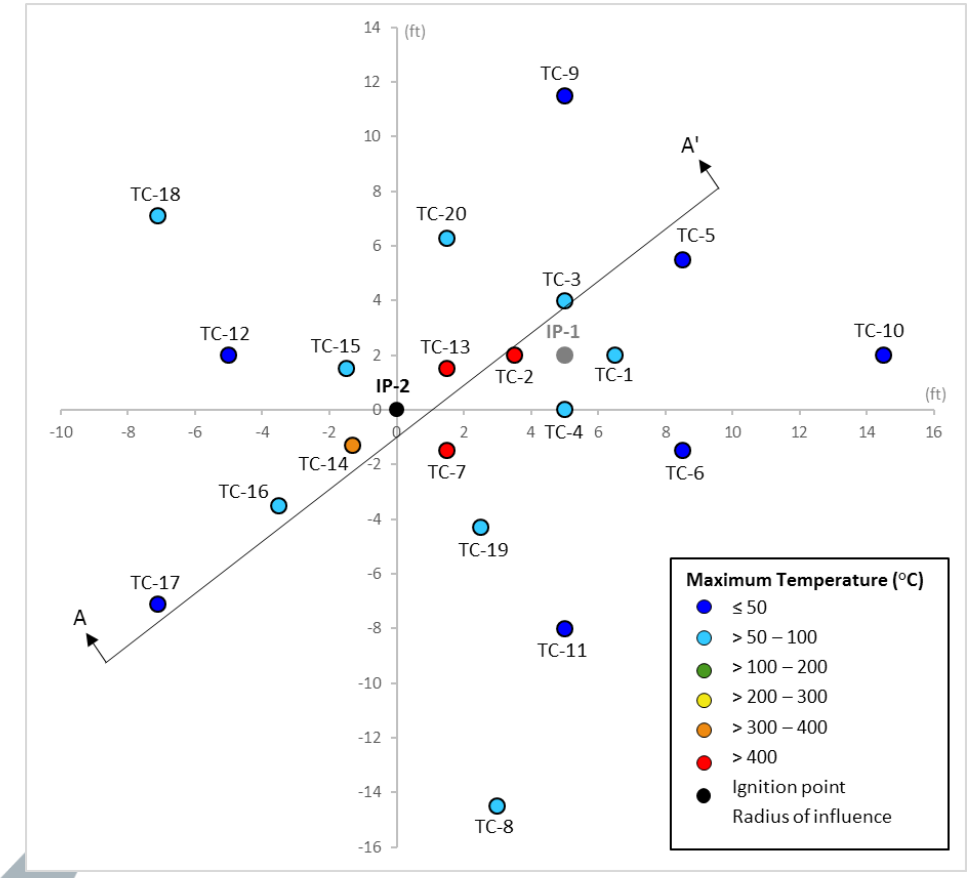
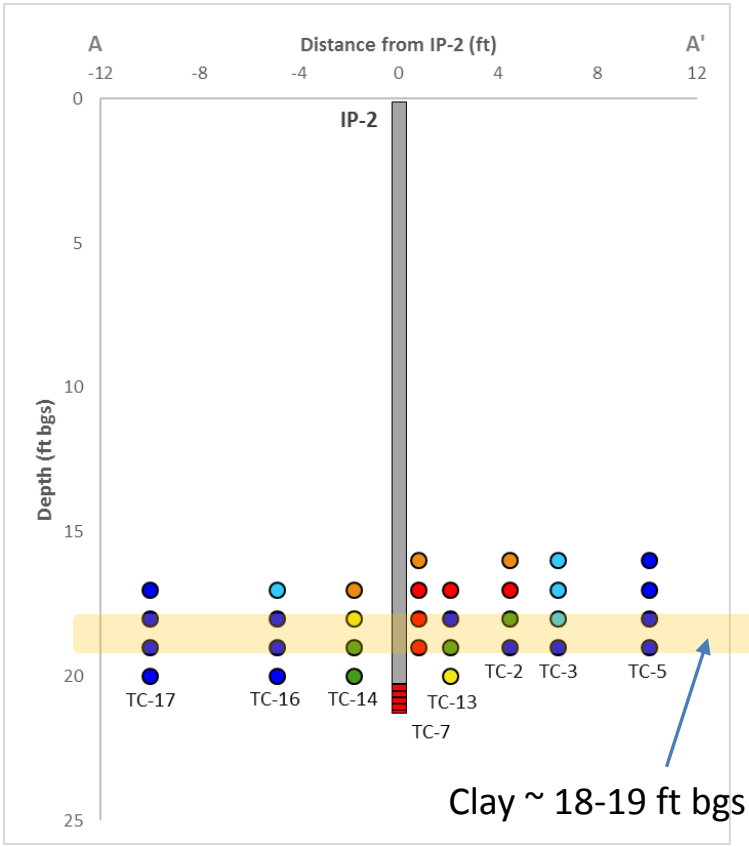
Pilot Test Results – Peak Temperatures

- Peak temperature data suggest preferential paths



- Combustion indeed occurred above the clay layer



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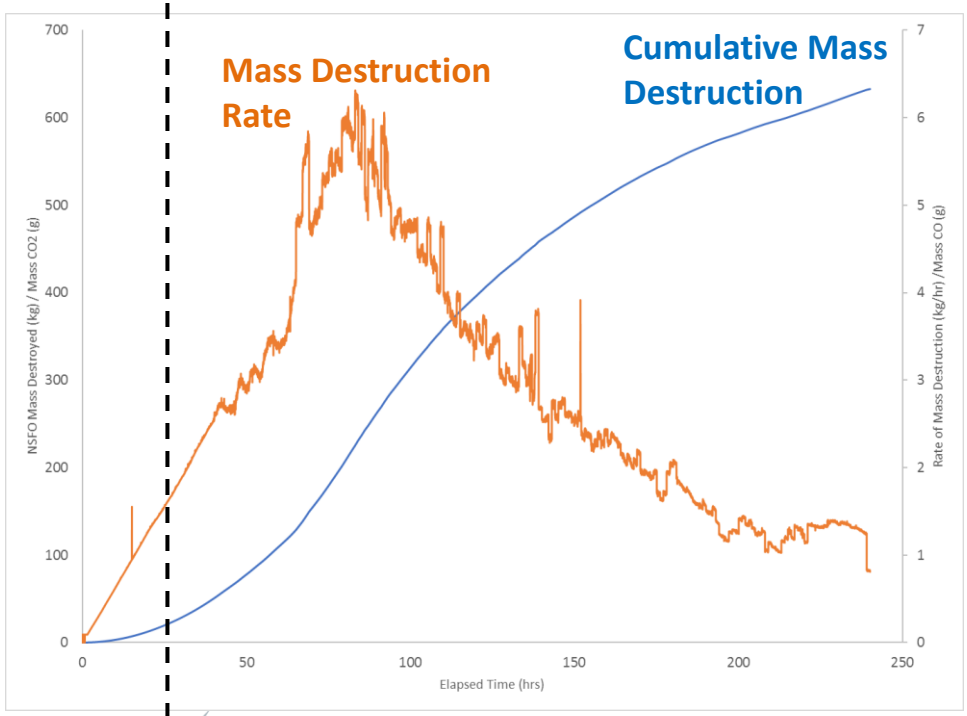
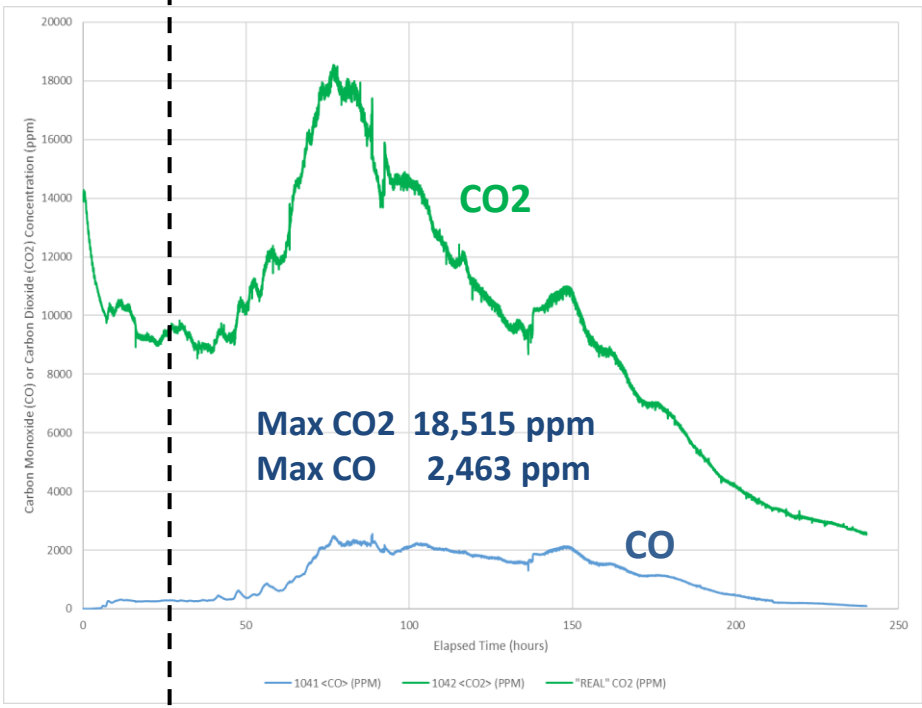
Pilot Test Results – Mass Removal and Gas Emissions

Initial Ignition (~26 hr)



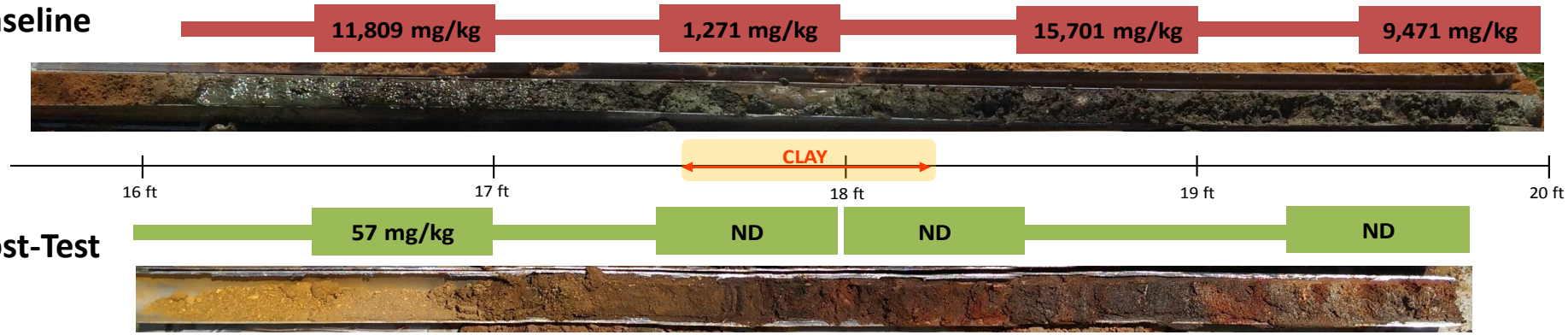
Initial Ignition (~ 26 hr)



Pilot Test Results – Soil Cores

1.5 ft to East (15 to 20 ft bgs)

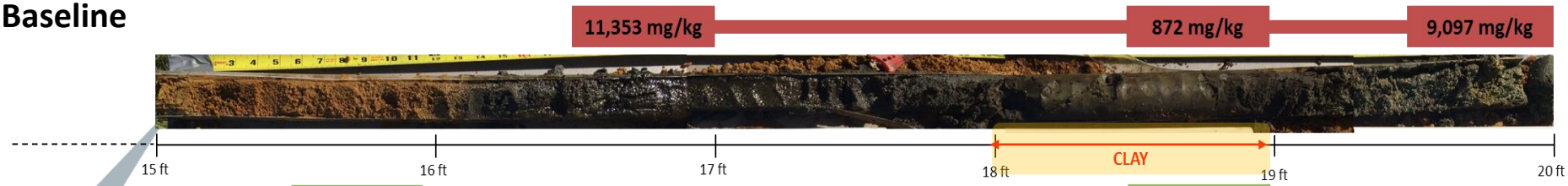
Baseline



Post-Test

5.5 ft to Northeast (15 to 20 ft bgs)

Baseline



Post-Test

Pilot Test Results – Soil Cores

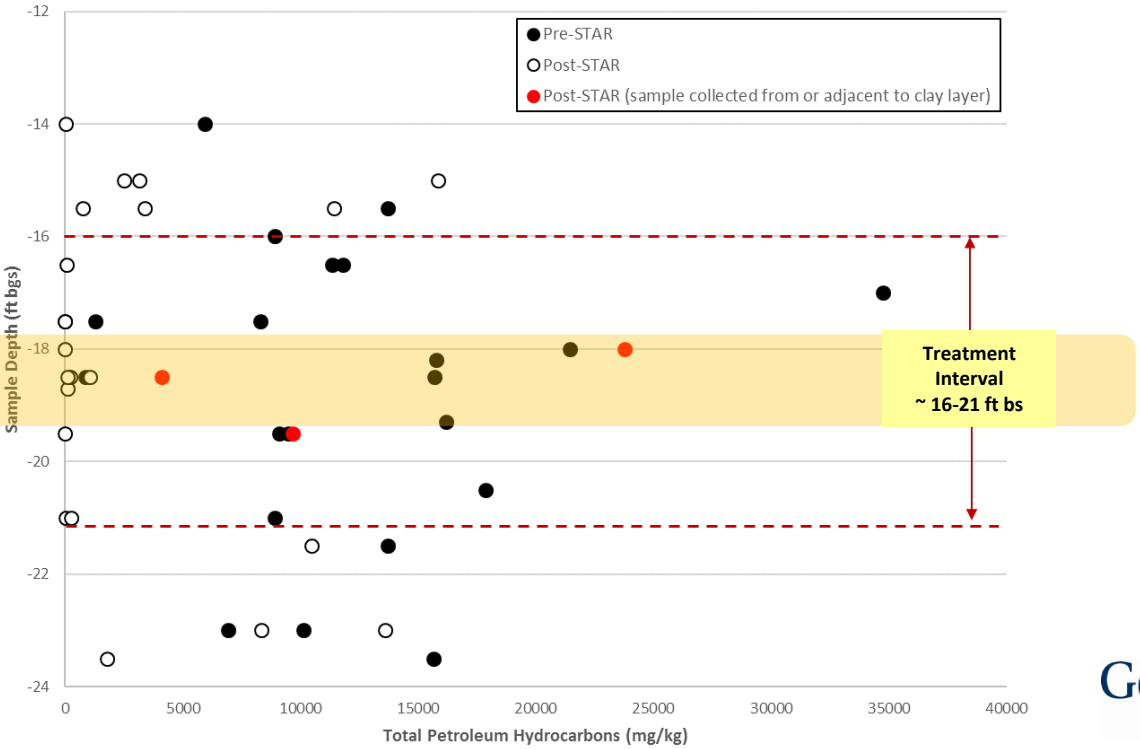
10 ft to Southeast (15 to 20 ft bgs)

Baseline

Post-Test

Summary View – distance and depth

Clay
~ 18-19 ft bgs



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Test Results Summary

- Treatment occurred above and below clay (below water table); but less effective within clay layer
- 17 of 22 co-located pre-/post-test samples above and below clay showed > 90% mass reduction
- Avg. (n=27) Pre-test soil TPH 14,400 mg/kg

  Avg. (n=17) Post-test soil* TPH 961 mg/kg → > 93% reduction

  [* excluding clay]
- Estimated 632.7 kg (174 gallons) of NSFO destroyed in 10 days
- Combustion extended to ~ 7.5 ft from the ignition well; but effective treatment area was not radial, likely due to lithology

Summary

- STAR achieved in situ smoldering combustion at the site
- Effective mass reduction and fairly complete combustion
- Subsurface lithology and NAPL distribution are critical factors
- A remedial alternative for sites with heavy oil contamination

Questions?

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STAR / STARx Field-Scale Projects

- **Coal tar site in NJ (ongoing)**
- **Former MGP in Illinois (Winter 2015)**
- **Former MGP in Michigan (Winter 2015)**
- **Navy Special Fuel Oil (Spring 2016)**
- **Former Refinery (Spring 2016)**
- **Several projects completed / underway in Europe, Australia, Taiwan:**
  - MGP Coal Tar
  - Former Coke Plants
  - Bunker C
  - Diesel

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