Thermal Remediation Services, Inc.

Electrical Resistance Heating for Rapid Remediation of DNAPL

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What is Electrical Resistance Heating?

- Takes common 3-phase electricity and directs it into the subsurface through electrodes
- Electrodes can be placed vertically to any depth or may be placed horizontally
- Once in the subsurface, the electrical energy resistively heats soil and groundwater
- Contaminants are removed by direct volatilization and *in situ* steam stripping

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Why Electrical Resistance Heating?

- Heating is uniform with no bypassed regions
- Heating is rapid – months vs. years
- Steam is produced *in situ*
- Preferentially heats tight soil lenses and DNAPL hot spots
- Cost effective: most commercial, full-scale sites range from $30-$90 per yds^3 (site specific)

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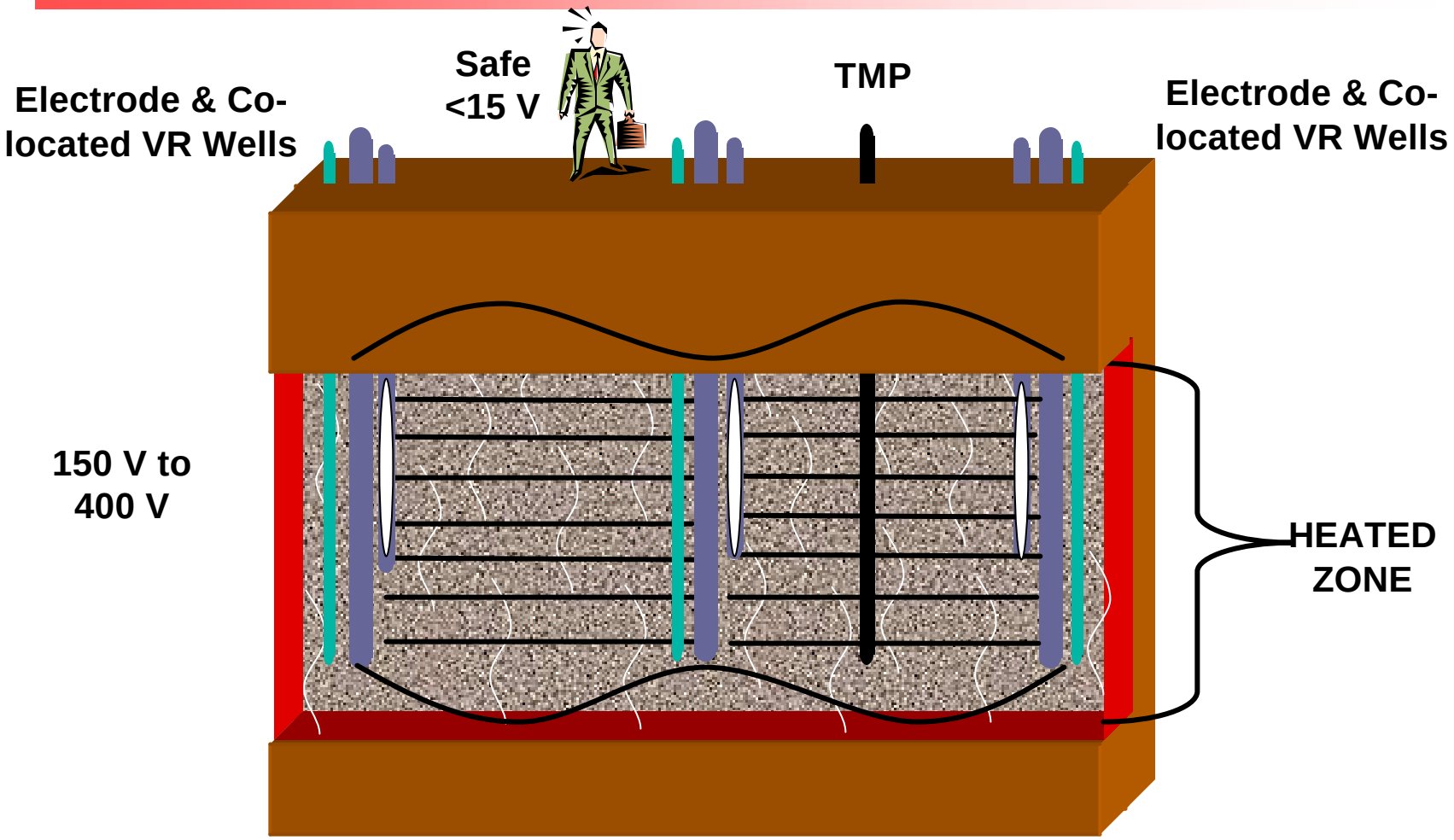
Applications

- Low permeability & heterogeneous lithologies
- DNAPL & LNAPL cleanups by aquifer and smear zone heating
- Heavy hydrocarbon mobilization
- Bioremediation enhancement
- Remediation underneath operating facilities
- Remediation in the presence of buried utilities and hazardous waste drums

In-Situ Steam Generation



1. Soil grains act as electrical resistors
2. Steam generation is uniform through the heated zone
3. Discrete intervals ca be heated

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Typical Surface Equipment

Photo Courtesy of Brown and Caldwell

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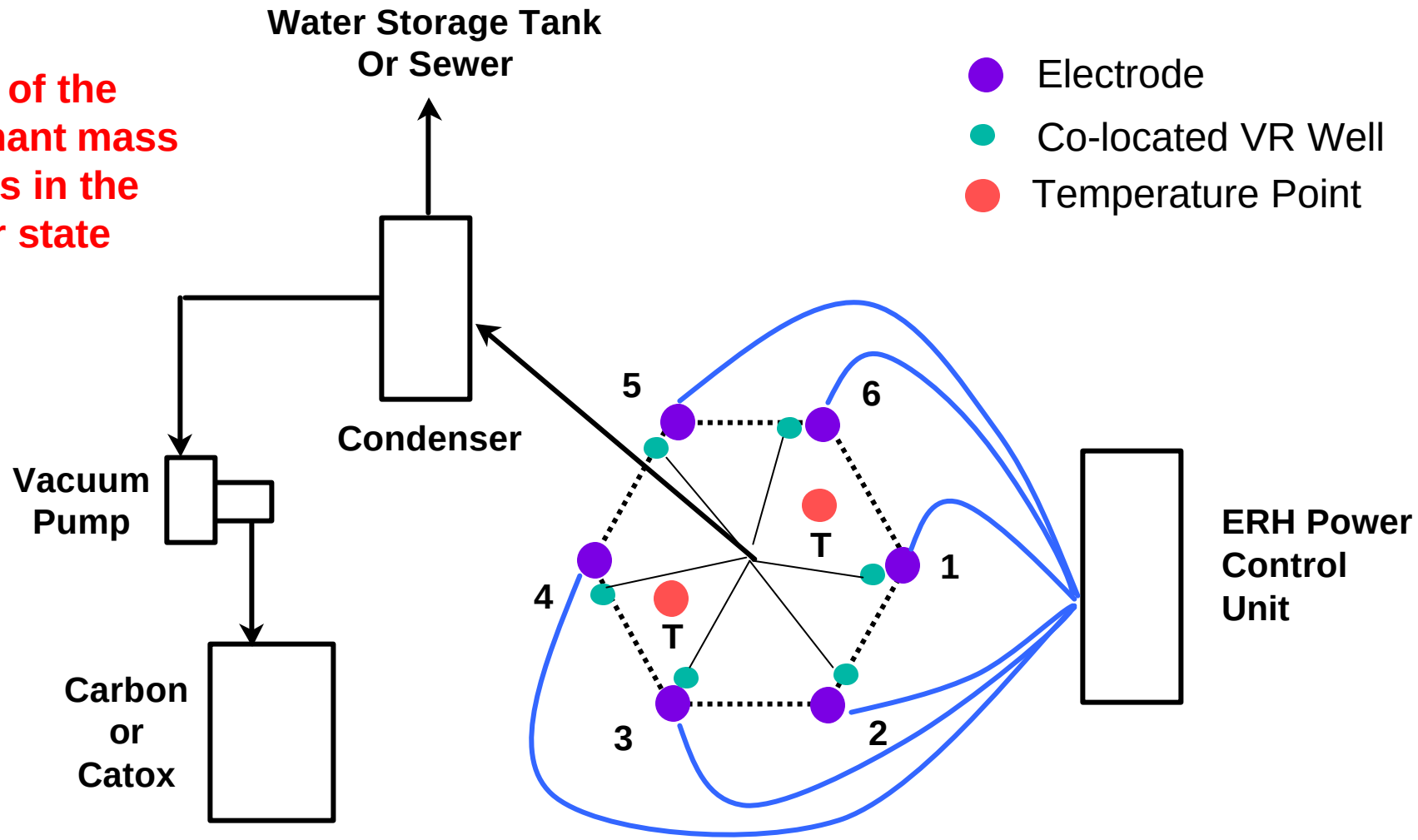
ERH 2000 kW PCU

Vapor Recovery System

>99% of the contaminant mass remains in the vapor state



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TCE DNAPL Remediation
Air Force Plant Four
Fort Worth, Texas

Photo Courtesy of URS

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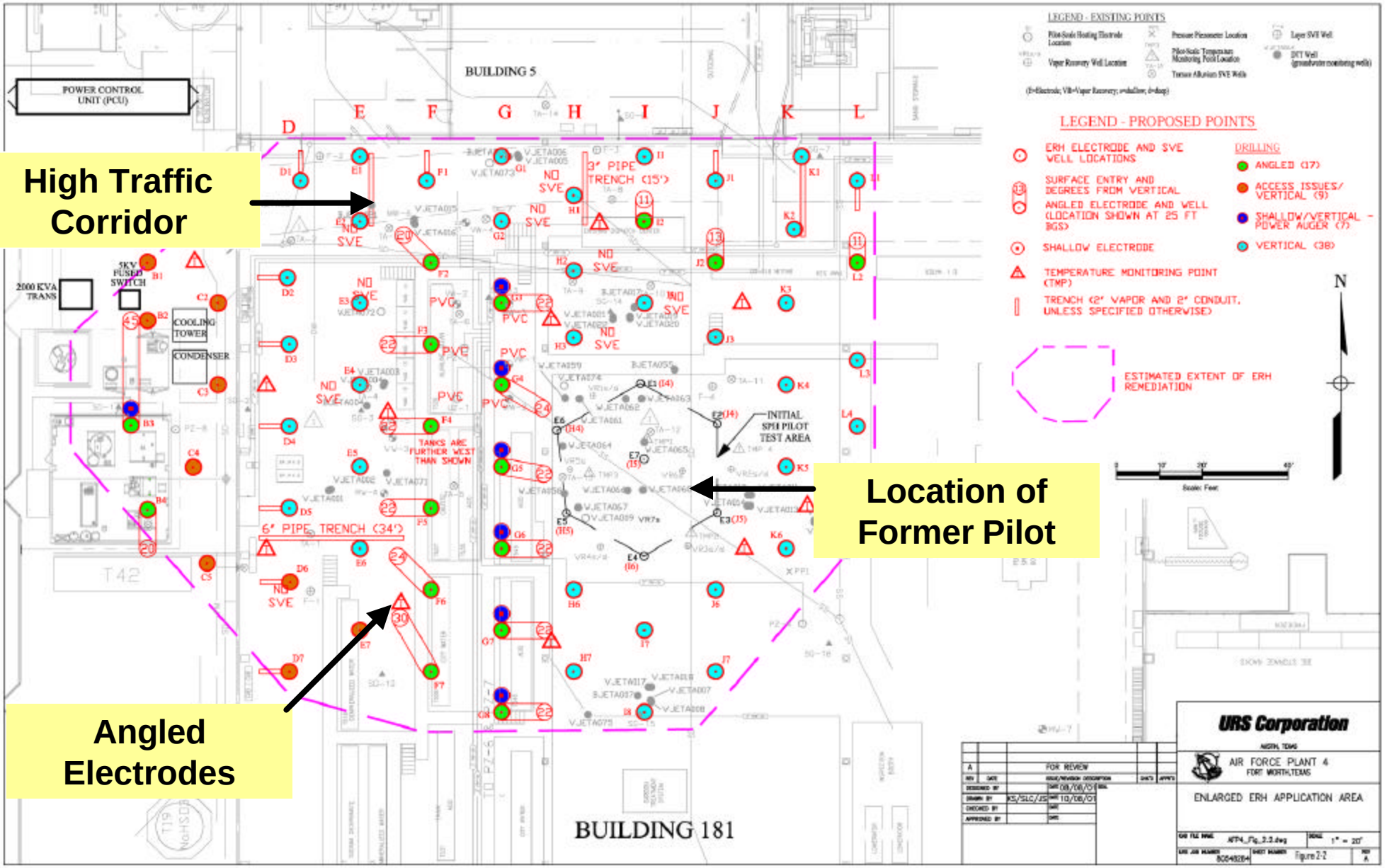
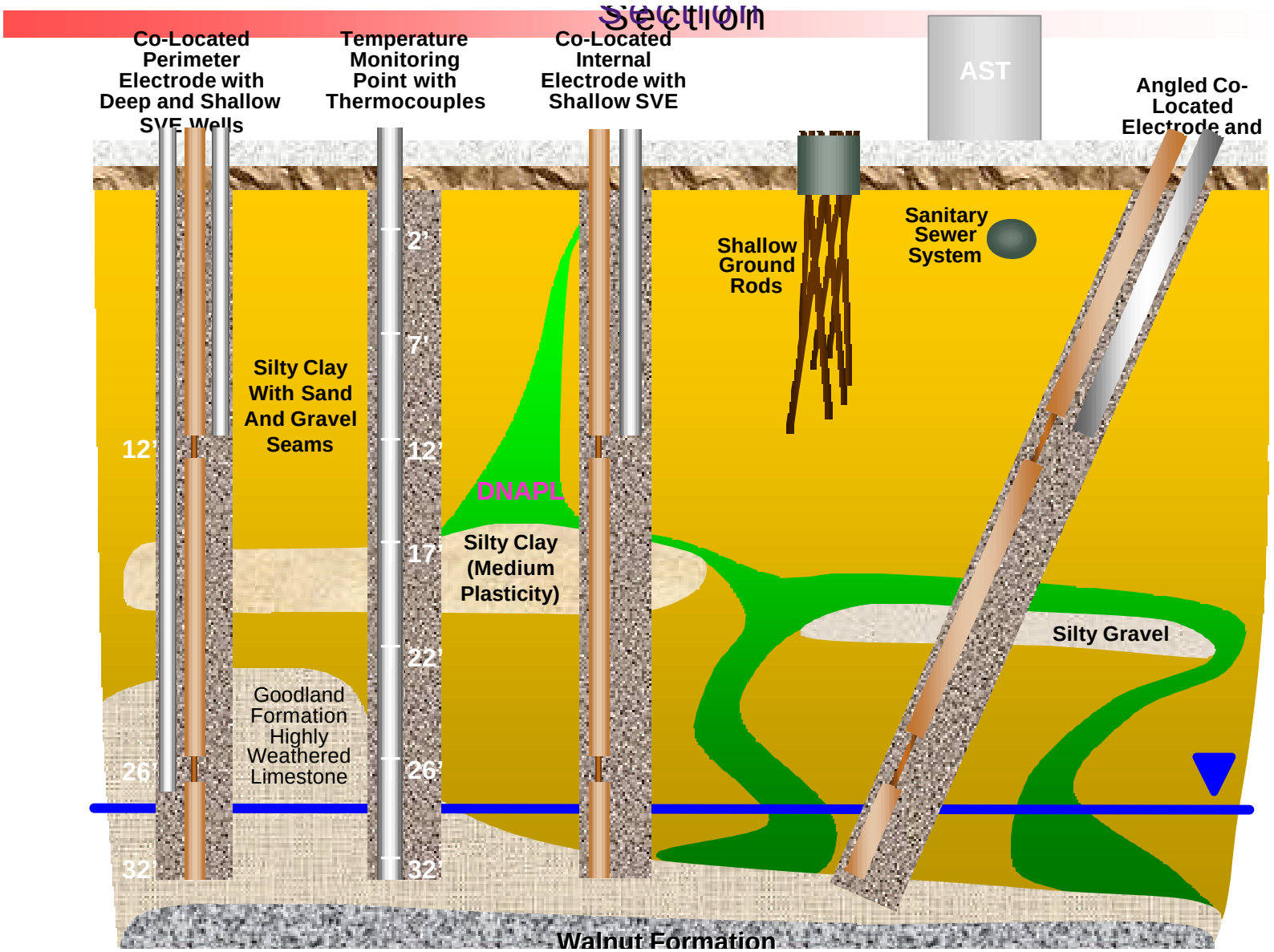
Full-Scale ERH at AF Plant 4

- Full-scale ERH covering 1/2 acre area inside and outside of Bldg. 181, manufacturing operations 24/7
- 70 electrodes and co-located VR wells installed in and around existing tanks, piping and equipment (32° angles)
- Heterogeneous silt, clay and gravel with a highly weathered limestone, competent bedrock at 32 ft bg
- Groundwater at 27 ft bg
- Electrodes electrically conductive 3 to 32 ft bg
- Two vapor and steam recovery intervals in perimeter electrodes
- ERH operations May to Aug 2002; reduced – Dec '02
- Goal – average 90% reduction based on a 95% UCL

Full-Scale ERH Layout



Full-Scale ERH Subsurface X-Section



ERH Remediation Beneath Air Force Plant Four

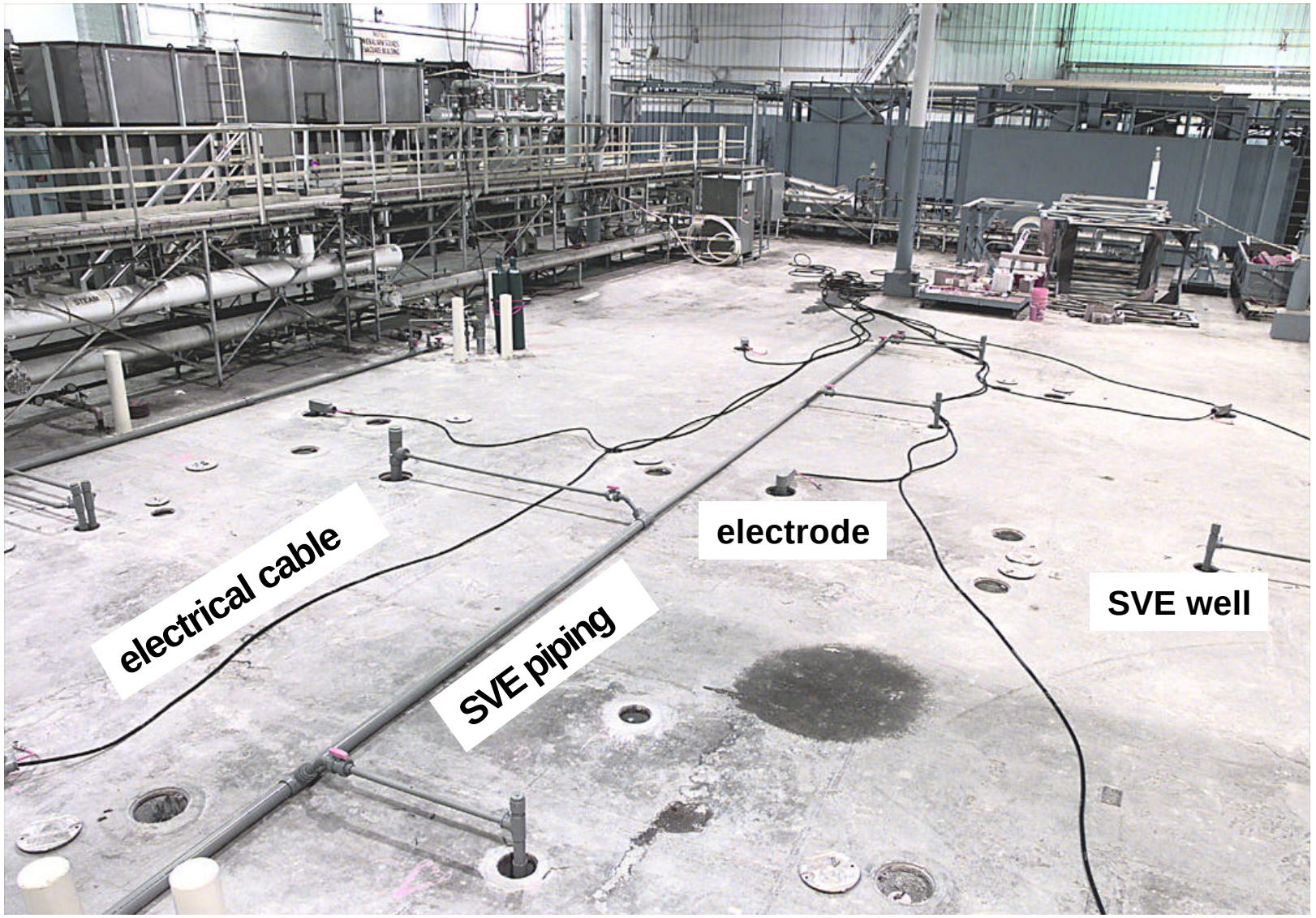


Photo Courtesy of URS

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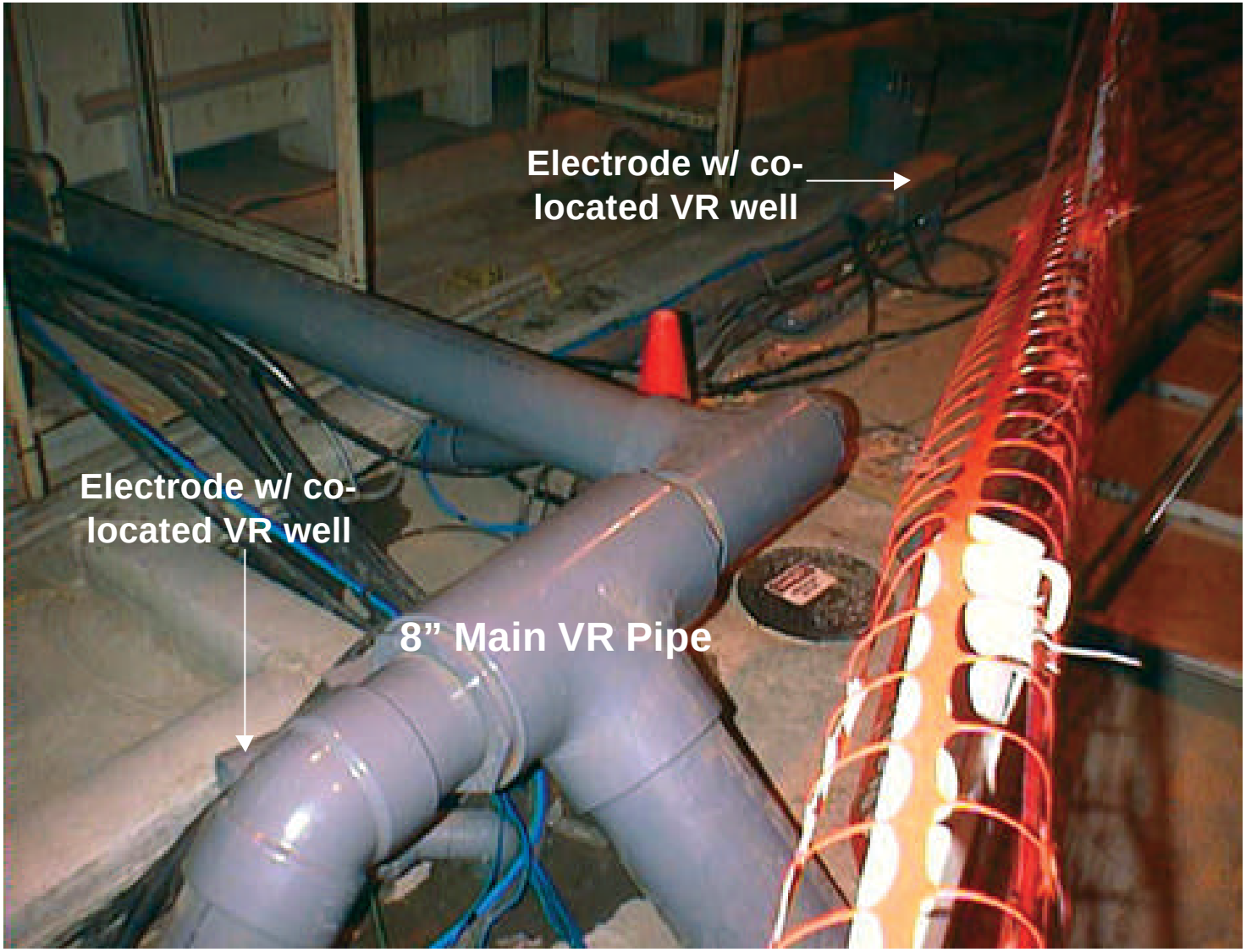
VR Piping Inside Bldg 181



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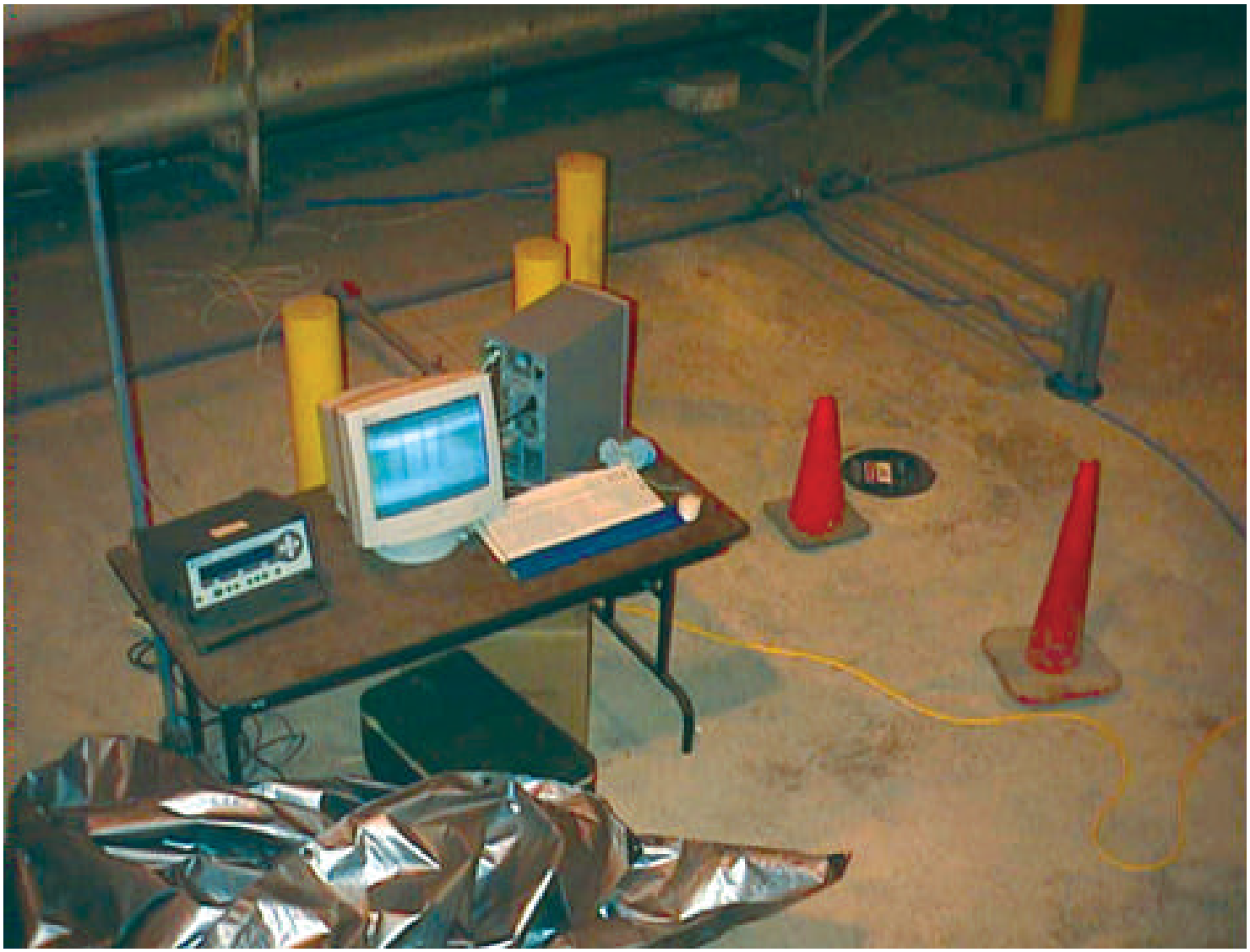
Close Up of ERH Electrode

Continuous Indoor Air Monitoring

- URS operated INNOVA System sampled air for TCE every 5 minutes
- Would shutdown ERH system if TCE >3 ppm
- Online remote monitoring
- Never exceeded background TCE concentrations inside Bldg. 181



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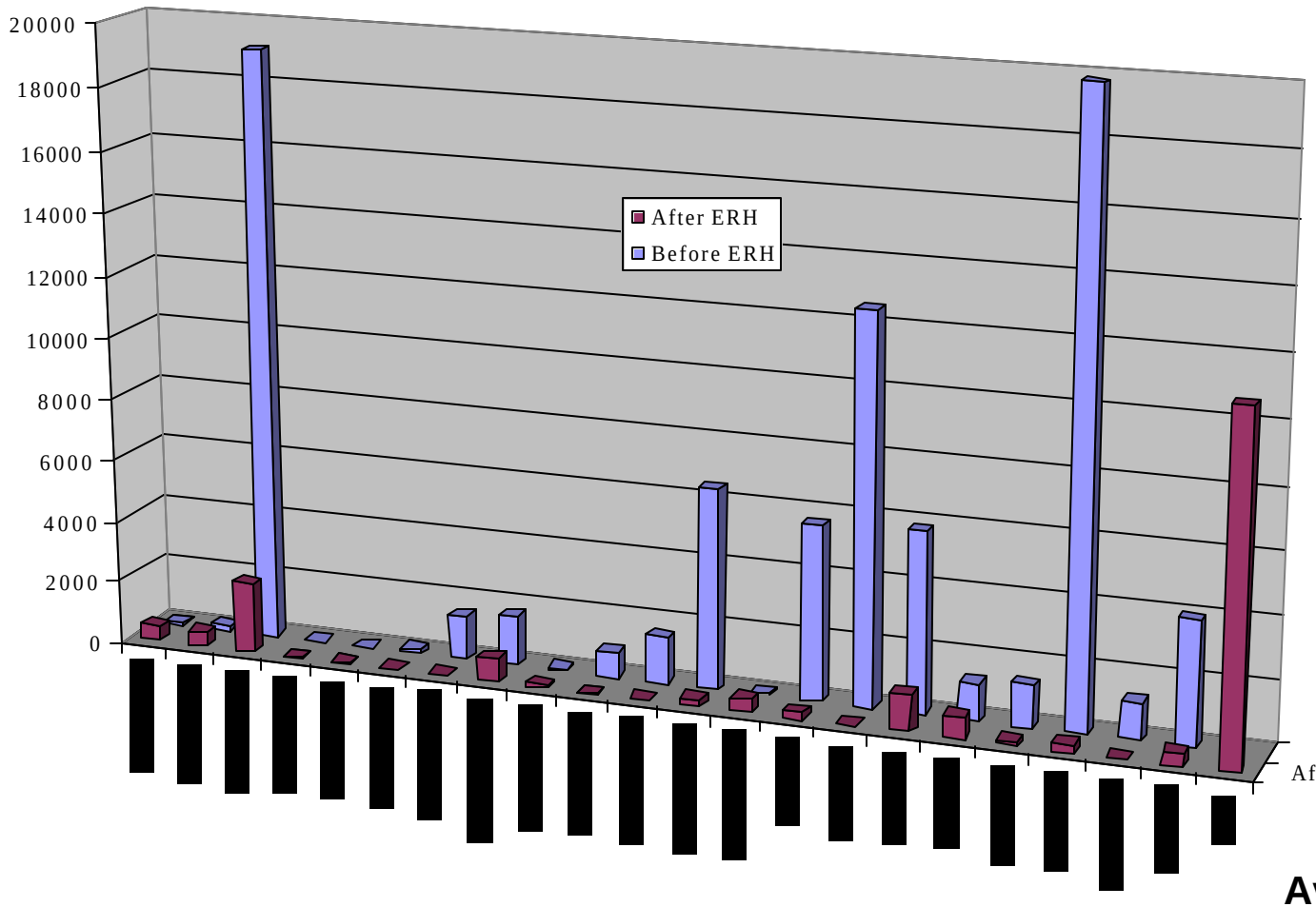
Final TCE Concentrations in Soil

TCE µg/kg



90% Average Reduction

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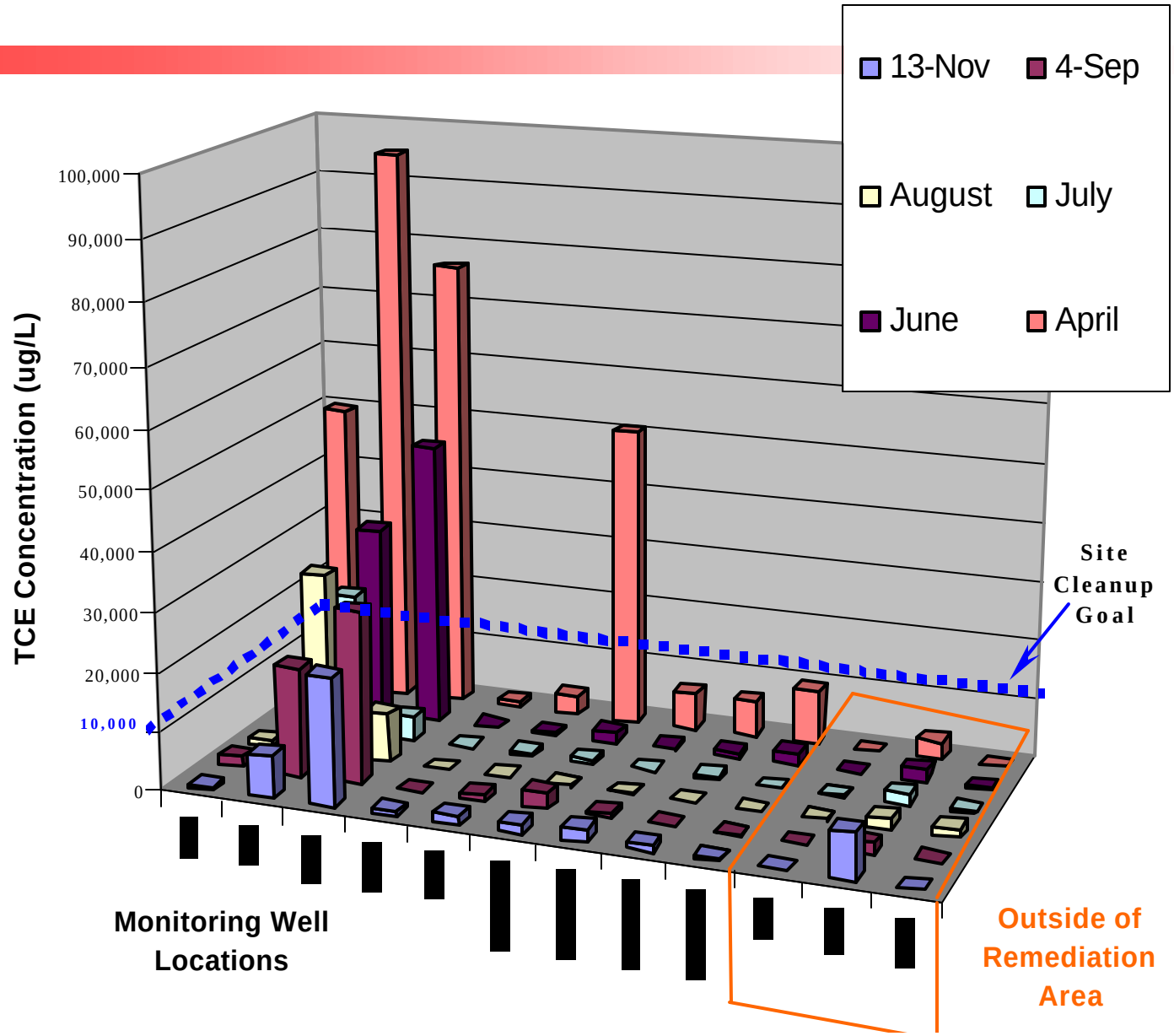
Final TCE Concentrations in Groundwater



Results at AF Plant 4

- Area & volume treated - 22,000 sq. ft. & 27,400 cubic yards – from May to Dec 2002
- Average weekly power input – 563 kW
- Recovered ~ 1,600 lbs. TCE
- Met groundwater goal following 4 months of ERH operations, ~ 93% average reduction in TCE concentrations in groundwater
- Met soil goal, 90% average reduction
- TCE concentrations never exceeded background levels of TCE in the indoor breathing space
- No impacts to manufacturing operations
- $57 per cubic yard

Polishing Mechanisms

- **Hydrolysis of Halogenated Alkanes**
  - Compounds such as TCA have a hydrolysis half-life of less than one day at steam temperatures.
- **Iron Reductive Dehalogenation**
  - Steel shot used as electrode backfill provides an iron source for reductive dehalogenation (iron filing wall)
- **Temperature Accelerates Reactions**
  - The above reaction rates are increased by factor of thousands at 100°C (Arrhenius Equation)
- **Bioremediation by Thermophiles**
  - Thermophilic bacteria are the most effective solvent dehalogenators and prefer 40-70°C

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