SGW-38571-VA
Revision 0

Electrocoagulation Treatability Test

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Project Hanford Management Contractor for the
U.S. Department of Energy under Contract DE-AC06-96RL13200

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Electrocoagulation Treatability Test

Scott Petersen, Fluor Hanford

July 29, 2008

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Soil & Groundwater Remediation Project

Introduction

- Objective: accelerate cleanup of contaminated groundwater at the 100-D Area
  - Remedial action objective (RAO): ≤ 20 µg/L Cr(VI) at compliance wells
- Approach: increase rate of groundwater extraction for the chromium plumes
  - Significant increase from current rate of ~150 gpm
- Ion Exchange is currently used as treatment portion of P&T systems
- Electrocoagulation is an alternative P&T treatment technology
  - Potential for effective treatment at a reduced cost

Test Objectives

- Determine effectiveness of Cr(VI) removal
  - Ability to meet ≤ 20 µg/L RAO
- Determine the volume and composition of the waste streams
  - Proper waste designation
- Assess the operational reliability and safety
- Assess overall treatment cost per volume of water treated
- Collect operational data to support potential scale-up

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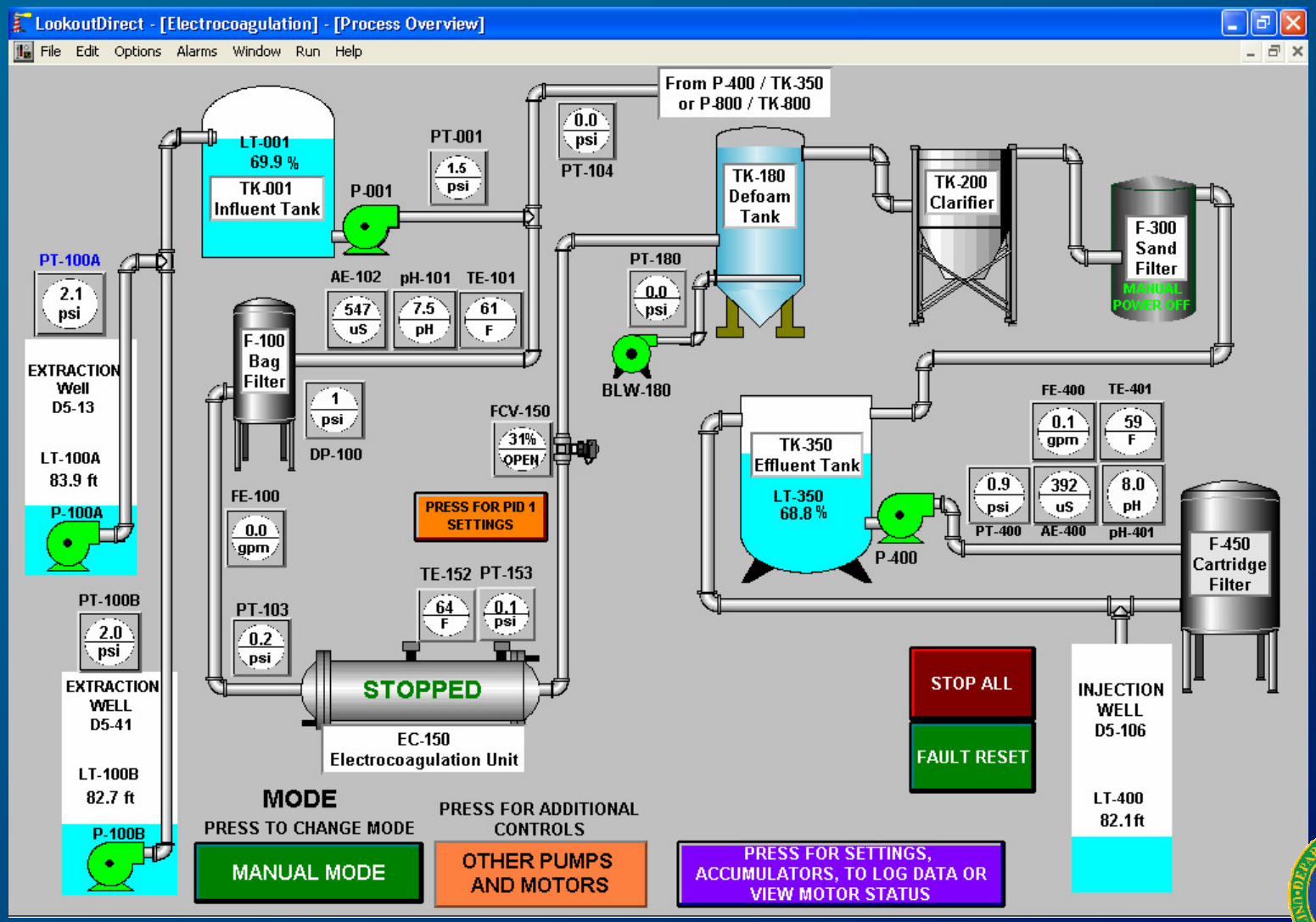
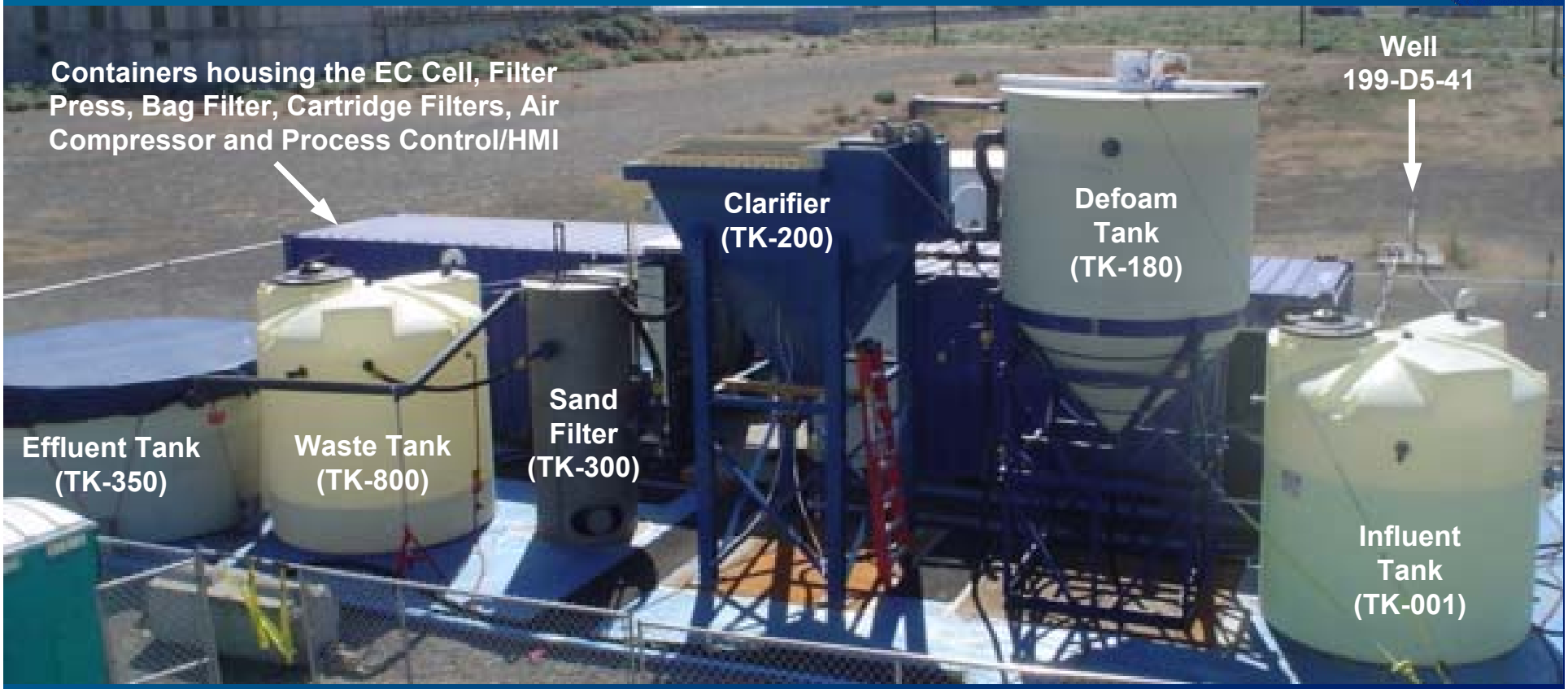
System Description

- EC unit uses direct current to corrode carbon-steel electrodes, providing soluble ferrous iron (Fe^{2+})
- Ferrous iron reacts with Cr(VI), producing insoluble Cr(III) and ferric hydroxide, $Fe(OH)_3$
- Aeration occurs in a defoam tank
  - Oxidize residual ferrous iron and begin flocculation
  - Gases are vented from the defoam tank to atmosphere
- Primary solids removal is achieved with an inclined plate gravity clarifier
  - Flocculant addition
- A gravity sand filter and a final polishing cartridge filter remove solids prior to injection

System Schematic



EC System



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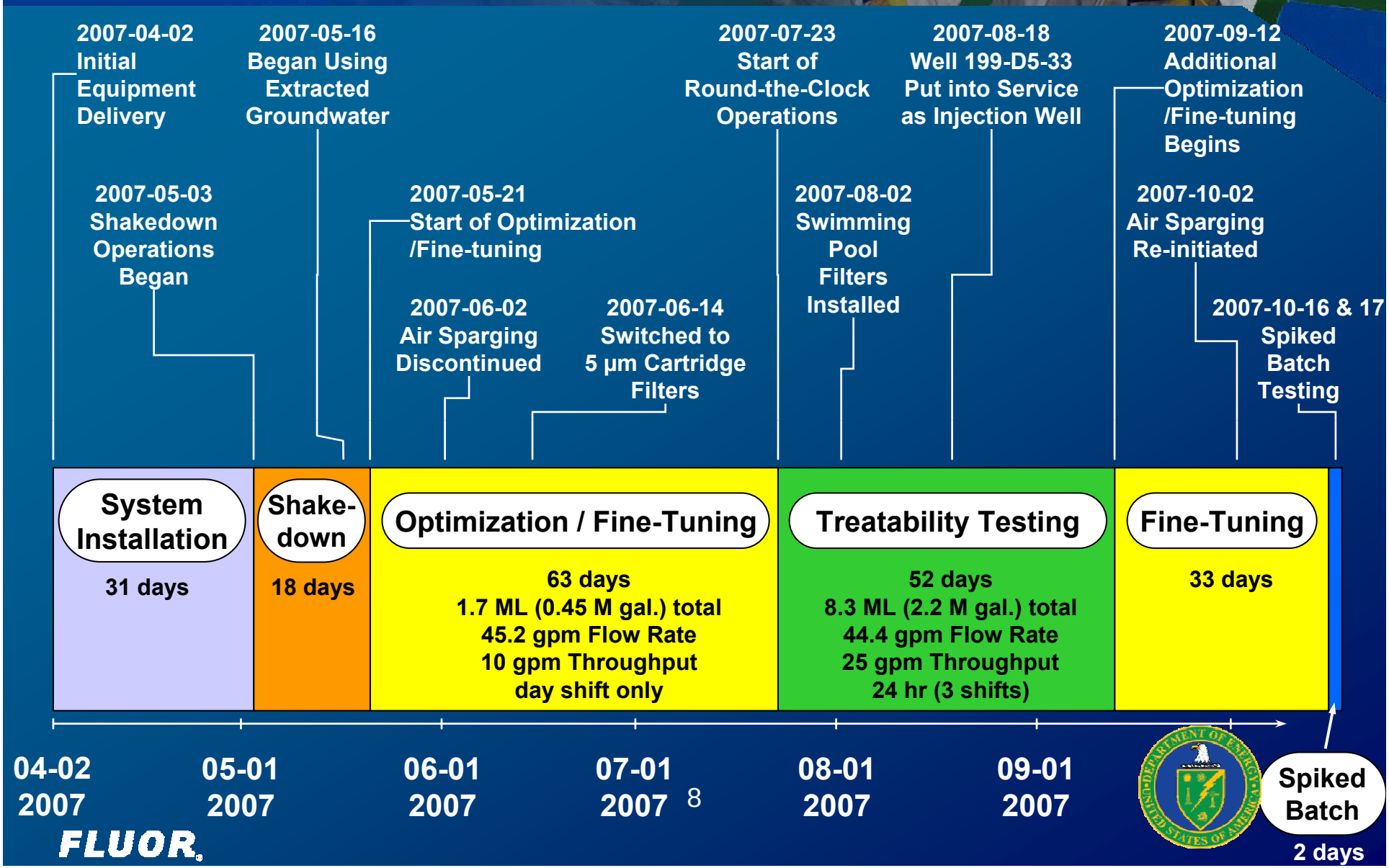
System Operation

- **Treatment capacity**
  - **50 gpm design**
  - **~45 gpm actual**
- **Three distinct operational phases:**
  - **EC system start-up and shakedown**
  - **EC system optimization/fine-tuning**
  - **Treatability testing**
- **Post-treatability-testing phase spiked batch testing**

Operational Timeline



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Deviations from Work Plan

- Used a second injection well (199-D5-33)
- Spiked batch tests to investigate treatment of high Cr(VI) concentrations
- No unattended operation
  - Attempted, but system was insufficiently robust
- No field duplicates analyzed in field assay process for Cr(VI)
- Frequency of offsite Cr(VI) analyses was monthly instead of weekly
- EC unit offgas not analyzed at offsite lab

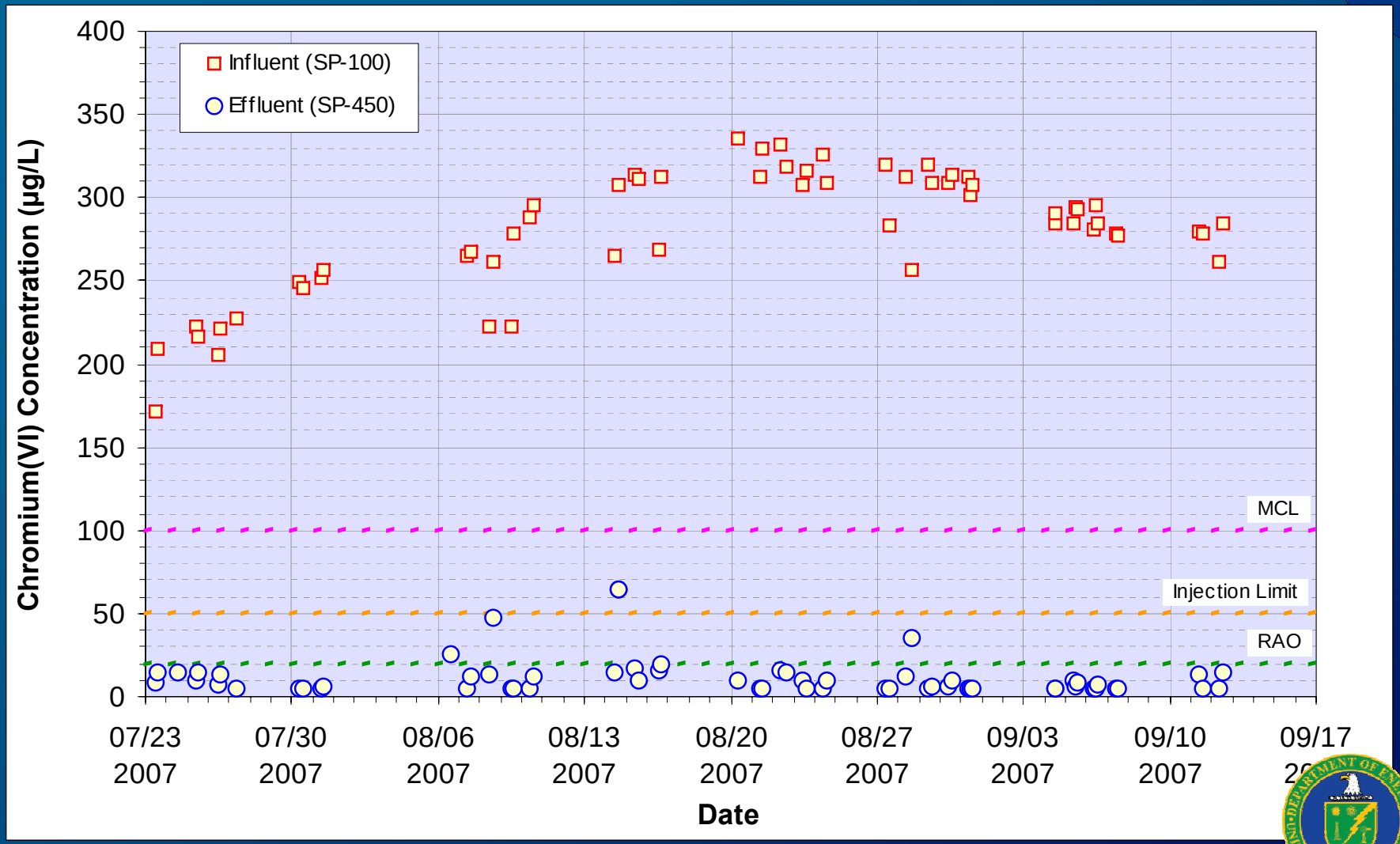
Modifications to System Equipment

- **No air sparging from June 2 to Oct. 2, 2007**
  - **High total iron & low Fe^{2+} implied poor solids separation**
  - **Vigorous agitation from sparging was theorized to inhibit floc formation**
  - **Later determined to be an inappropriate action**
- **Wastewater recycle pump reconfigured**
  - **Used sump pump suspended at mid-tank to avoid pumping settled solids**
- **Pump added to clarifier**
  - **Recirculated sludge as "seed" for floc formation and settling**

Modifications to System Equipment (continued)

- **Pair of pool sand filters installed between effluent tank and cartridge filter**
  - **Supplemental filtering to extend cartridge filter life**
  - **On-line backwashing capability**
  - **Used finer, more angular sand than the gravity sand filter**
- **Larger pore size cartridge filter elements were used**
  - **Used 5 µm filter elements instead of 1 µm**

Treatability Results – Cr(VI)



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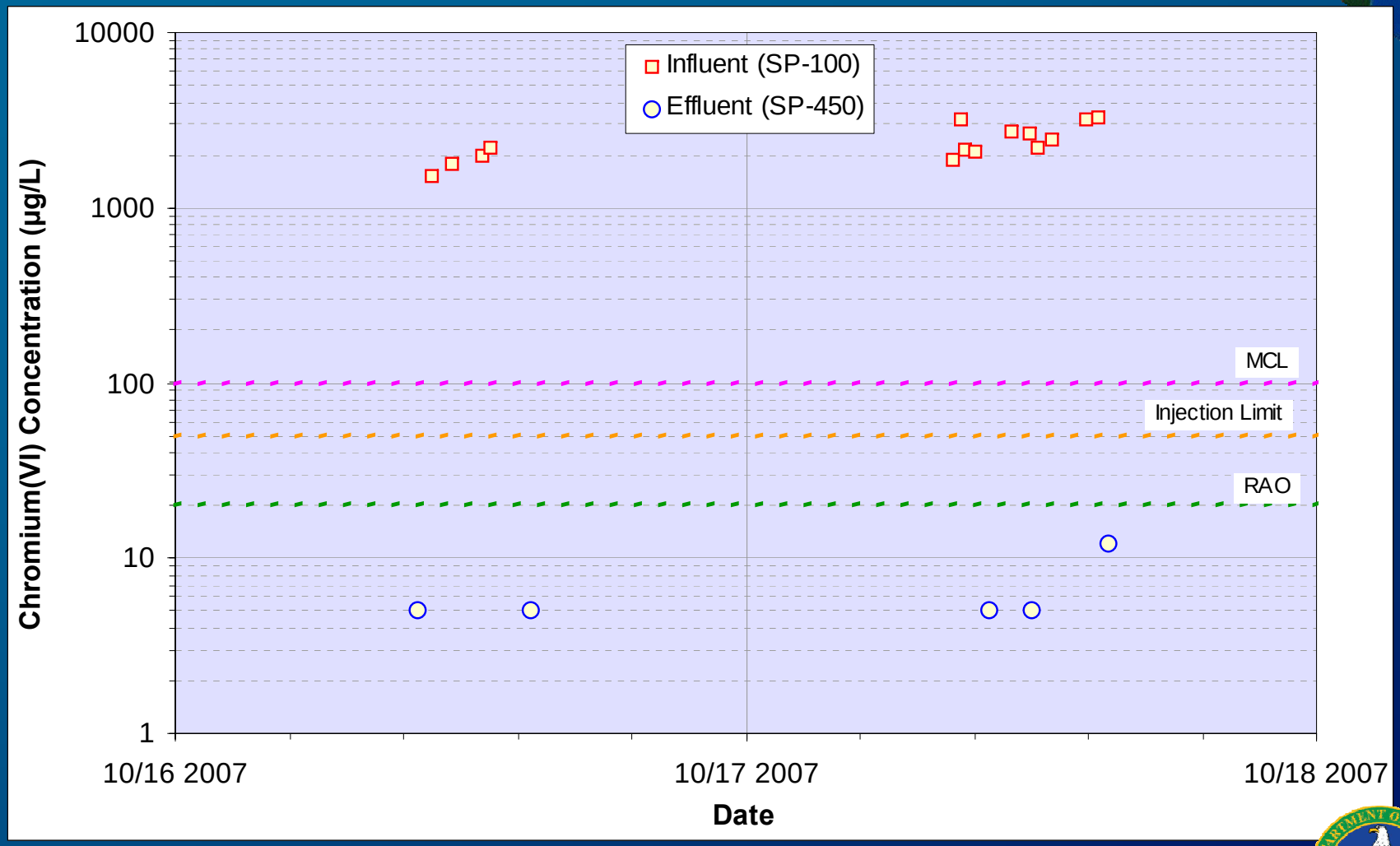
Post Treatability Phase – High Chromium Batch Results



Note logarithmic scale on y-axis

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Treatability Results – Waste Designation

- No solid samples exceeded the TCLP extract limits for designation as dangerous waste
- No solid sample pH results exceeded the limits for designation as a corrosive waste
- Paint filter test showed free liquid in two out of three solid samples assayed
  - Easily addressed by draining and/or using adsorbent

Treatability Results – Solids Generation Rate

- **Solid secondary waste generated at a nominal rate of 0.65 gallons of solids per 1000 gallons treated**
  - **Basis: 2.8 M gal. treated and 33 drums of non-PPE solid waste generated over the entire project duration**
  - **42 gallons of solids total per day**
  - **36% was filter press solids, 6% was sand from sand filters, and 58% was cartridge filter elements**

Treatability Results – Operational Reliability

- **The system was not able to continuously operate unattended**
- **The system regularly required suspension of injection and recycling of effluent**
  - **High concentrations of Cr(VI) and/or total iron in effluent necessitated multi-pass processing**
- **Poor solids separation and high effluent iron concentrations led to injection well fouling**
- **Operational reliability issues in two areas**
  - **EC unit control and scaling**
  - **Sensitivity of the solid separation process to operational conditions**

Treatability Results – EC Unit Operational Challenges

- Passivation of electrode surfaces
  - Reaction byproducts (e.g., magnetite) accumulate on surface
  - Used current polarity reversal to minimize passivation
- Polarity reversal was insufficient to prevent electrode passivation & scale buildup on electrode surface
  - Polarity reversed at a 7.5 minute cycle
- Scale buildup on electrode surface required periodic mechanical scraping
- Acid cleaning of electrodes was performed
  - Ineffective at scale removal
- High amperage "burn off"
  - Appeared to be ineffective at scale removal
- Impacted Cr(VI) removal performance and maintenance

Treatability Results – Solids Separation Operational Challenges

- **Lack of representative analysis for ferrous iron in the process stream**
  - **Improper field assay procedure and high detection limits**
  - **Resulted in misinterpretation of system conditions**
    - **Led to discontinuation of air sparging**
- **Insufficient oxidation of ferrous iron (no air sparging)**
  - **Resulted in poor solids separation**
  - **Promoted growth and biofouling by iron bacteria**
  - **Possible downstream oxidation and precipitation**

Treatability Results – Solids Separation Operational Challenges

- **Insufficient separation and removal of solids**
  - **Non-optimal coagulant/flocculant dosage**
  - **Inadequate mixing (in terms of duration and mixer speed)**
  - **Insufficient residence time for particle settling in the clarifier**
- **Continuously backwashed sand filter was ineffective**
- **Primary impact was chronic fouling of injection wells**

Comparison to Industry

- EC has been applied in industry for a variety of pollutants
  - Heavy metals, dye, organics, suspended solids
- Industrial EC systems tend to be reliable
  - Effluent can be discharged to the sewer (versus injection to groundwater); effluent standards (e.g., 100 µg/L) are less demanding
  - Treated streams are presumably well characterized by laboratory studies and process knowledge
  - EC design, while largely empirical, is rigorous enough to provide a reliable system for the industrial scenario

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Treatability Results – Cost

- **Total Project Cost: $2,468,035**
- **EC treatability study was funded under DOE's Office of Environmental Management (EM-22) Innovative Technology Program**
  - **$2,049,600**
- **Project EM-30 Program funding was augmented with some site-specific funding**
  - **$418,435**

Costs (continued)

- **Cost break-down by activity, funding source and cost type**

Contracts (EM-22 Funds)	*Cost*	*Cost Category*
Design, procurement, fabrication, installation, and operation	$ 906,762	Capital
Electrical and site preparation	$ 51,577	Capital
Well piping; electrical, fence, and generator	$ 154,813	Capital
Subcontract technical support	$ 68,704	Excluded
Injection well	$ 67,745	Excluded
Fluor Hanford (EM-22 Funds)		
Labor	$ 469,900	O&M
Material and equipment	$ 25,200	O&M
Training	$ 4,200	O&M
Waste Sampling and Characterization Facility laboratory	$ 29,000	O&M
Other direct costs	$ 1,700	O&M
Subtotal	$ 1,779,600	N/A
Burden	$ 270,000	Excluded
EM-22 Total	$ 2,049,600	N/A
EM-30 Funds		
Sampling support (contract)	$ 71,908	O&M
Electrical power (Fluor Hanford)	$ 1,640	O&M
Waste disposal (Fluor Hanford)	$ 6,200	O&M
Overhead (Fluor Hanford)	$ 279,300	Excluded
Subtotal	$ 359,048	N/A
Burden	$ 59,387	Excluded
EM-30 Total	$ 418,435	N/A
Grand Total (project cost, no exclusions)	$ 2,468,035	N/A
Total Capital	$ 1,113,152	N/A
Total O & M	$ 609,748	N/A
Total Capital + O&M	$ 1,722,900	N/A

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Treatability Results – Cost
(continued)

- **Total treatment Cost: $1,722,900**
  - Excluded injection well, subcontract support, overhead, & burden costs
  - Capital Cost: $1,113,152, O&M Cost: $609,748
- **Volumes treated**
  - Treatability-testing phase: 8.3 ML (2.2 M gal.)
  - Total project: 10.3 ML (2.8 M gal.)
- **Operation costs per unit volume treated**
  - Treatability-testing phase basis: $0.07/L ($0.28/gal.)
  - Total project basis: $0.06/L ($0.22/gal.)
- **Total (Capital + O&M) cost per unit volume**
  - Treatability-testing phase basis: $0.21/L ($0.78/gal.)
  - Total project basis: $0.17/L ($0.63/gal.)

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Treatability Results – Scale-Up

- Operational data from treatability-testing phase provide information to consider when evaluating the EC technology for full-scale operation at Hanford
- Spiked batch testing demonstrated that higher influent chromate concentrations can be effectively treated
- Suitability of data for scale-up is diminished by operational problems
- Scale-up analysis will need to consider recommendations from this study

Conclusions

- EC system met Cr(VI) performance goals
  - Often required multi-pass (recycle) treatment
- Solid secondary waste met toxicity & corrosivity criteria for disposal; with engineering/operational improvements, free liquid criterion could be met
- As implemented, EC system was not reliable
- EC technology has potential, but would require better design and implementation than realized in this test
  - More pre-design information (laboratory/bench-scale tests) would have led to an improved test

Process Improvement Considerations

- **Additional assessment of EC unit design and operating parameters (e.g., power settings and polarity reversals)**
  - **Maintain consistent/stable ferrous iron production and resultant reduction of Cr(VI)**
  - **Minimize electrode passivation and/or fouling to improve Cr(VI) removal performance and minimize maintenance down-time**
    - **Increase the frequency of polarity reversal (e.g., 30 to 60 sec.)**
    - **Minimize amperage to EC unit to minimize iron scale**
    - **Control influent pH to minimize hardness scale**
  - **Minimize energy consumption**

Process Improvement Considerations
(continued)

- **Re-design treatment train to improve solids removal**
  - **Effective aeration to oxidize excess ferrous iron**
    - **Immediately downstream of EC unit**
  - **Effective removal of iron solids**
    - **Properly designed/sized equipment (e.g., clarifier, sand filters)**
    - **Optimized water treatment chemical dosing**
  - **Suitable disposal path for excess water treatment chemicals**
    - **Avoid overdosing through in-process usage of excess**
  - **Understand process stream geochemistry**
    - **pH and temperature impacts on solids precipitation (and Cr(VI) removal performance)**
  - **Automated on-line pH adjustment**

Process Improvement Considerations
(continued)

- **Optimize treatment train for unattended automated operation**
  - **Sensors and controls to automate required alterations in the electrical current and polarity reversal of the EC cell**
  - **On-line sensors to monitor solids, iron (total and ferrous), and hexavalent chromium**
  - **System disinfection features to control microbial/algal growth**
    - **Closed tanks**
    - **Opaque tanks**

Questions

- **Questions?**
- **Discussion?**