Perchlorate Treatment Technologies:

Biodegradation Prototype Thermal Decomposition

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APPLIED RESEARCH ASSOCIATES, INC.

An Employee-Owned Company

Overview

- **Optimization of the Thiokol Prototype Biodegradation Process**
  - **Conversion to Low-Cost Nutrient**
  - **Cost and Performance Impact**
  - **Co-Contaminant Studies**
- **Full-Scale Groundwater Treatment Plant for Henderson, Nevada**
- **EPA Thermal Treatment Project**

ARA Process

- **Optimized for High Concentration Effluents**
  - **1to >5,000 mg/liter perchlorate**
- **Robust in High TDS, Highly Contaminated Effluents**
- **Suspended-Growth Process**
- **Continuous-Stirred Tank-Reactors (CSTR)**
  - **Simple control and operation**
  - **Adaptable to a wide range of flow/residence times**
  - **Bio-accumulation of potential inhibitors is mitigated**
- **Perchlorate Reduced with Many Different Nutrients**

Thiokol Prototype

- **Operational Since Dec 1997**
  - **Thiokol Operated Under CRDA with AFRL**
  - **Never Re-inoculated**
- **Effluent Properties**
  - **High Salt (KCl) ~2%**
  - **High Nitrate & Nitrite**
  - **Other Co-Contaminants**
  - **Ammonium Perchlorate**
- **Performance in 1999**
  - **15,400 lbs ClO_4- Reduced**
  - **300-4600 mg/L ClO_4- feed**

Nutrient Evaluation

- **Prototype Design Basis**
  - **Brewer's Yeast and Cheese Whey Blend (~30:70)**
  - **Nutrient Operations Were Problematic**
    - **Pre-mix dry nutrient in batch mode**
    - **Suspended solids caused plugging problems**
    - **Difficult to prevent fungal and microbial growth**
    - **Cost $0.50 to $1.00 per pound**
- **Alternate Nutrients**
  - **Low-Cost, Stable, Liquid, Pumpable, High Nutrient Value**
  - **Food Industry Byproducts**

Nutrient Evaluation

- **Laboratory Bottle Test**
  - Batch inoculation
  - Conduct in 125 ml bottles
  - Evaluate single variables
  - Indicator of CSTR performance
- **Many Nutrients Work**
  - Acetate, alcohols, sugars, starches, proteins, carbohydrates
- **Two Candidates Evaluated**
  - Fruit Juice Waste
  - Carbohydrate Byproduct (CBP)

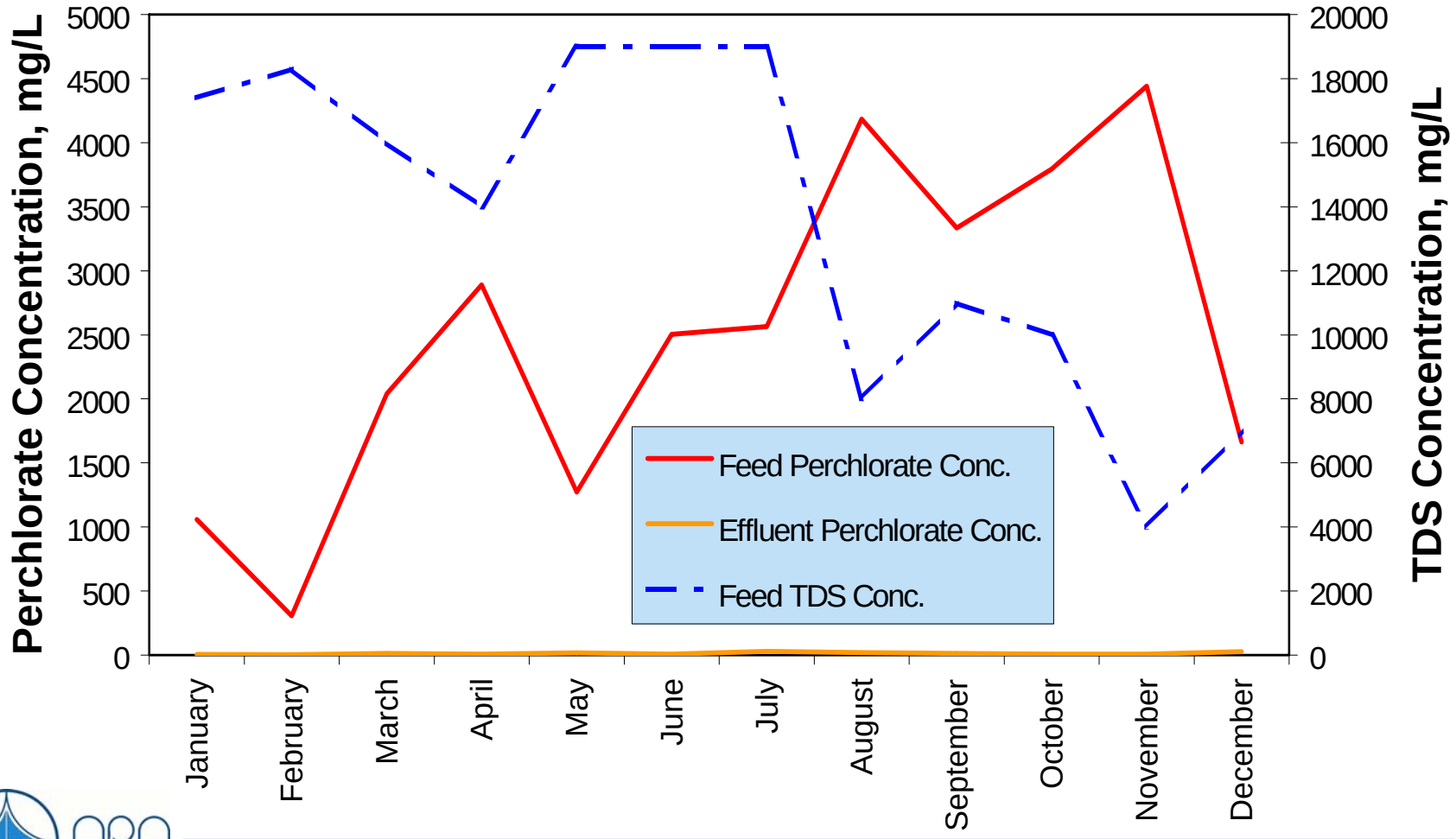
Nutrient Evaluation

- **Fruit Juice Waste**
  - **Sugar-Based Effluent**
  - **Relatively Low Nutrient Value (~4%)**
  - **Low Cost: Available for Transportation Cost**
  - **Potential for Fermentation**
- **Carbohydrate Byproduct (CBP)**
  - **Multi-Component (Proteins, Sugars, Organic Acids, Etc.)**
  - **High Nutrient Value (~50%)**
    - **Nutrient value based on biodegradable organic content**
  - **Low Cost (~$25 per Ton) and Commercially Available**
  - **Stable, Storable, Pumpable Liquid**

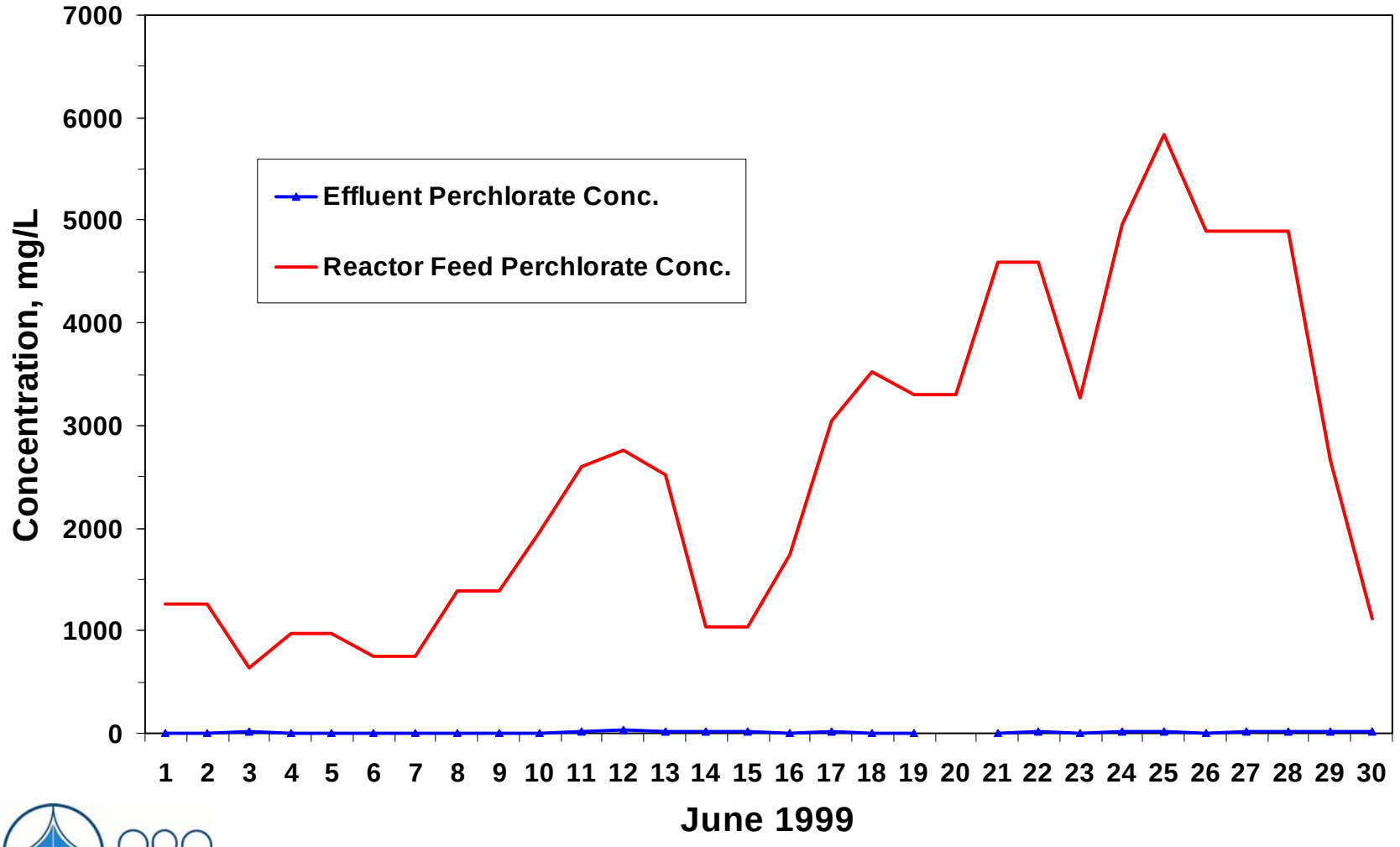
Prototype Demonstration

- **Carbohydrate Byproduct (CBP) Selected**
  - **CSTR Testing Confirmed Performance**
- **Incremental Conversion Accomplished May 1999**
  - **Yeast-Whey → Whey-CBP → Straight CBP**
  - **No Equipment Modifications Were Performed**
  - **CBP was Diluted for Operational Considerations**
- **Prototype Performance Was Unaffected**
  - **Achieved Near Complete Perchlorate Reduction**
  - **Mitigated Contamination of Nutrient Feed**
  - **Nutrient & Chemical Costs Decreased by >90%**

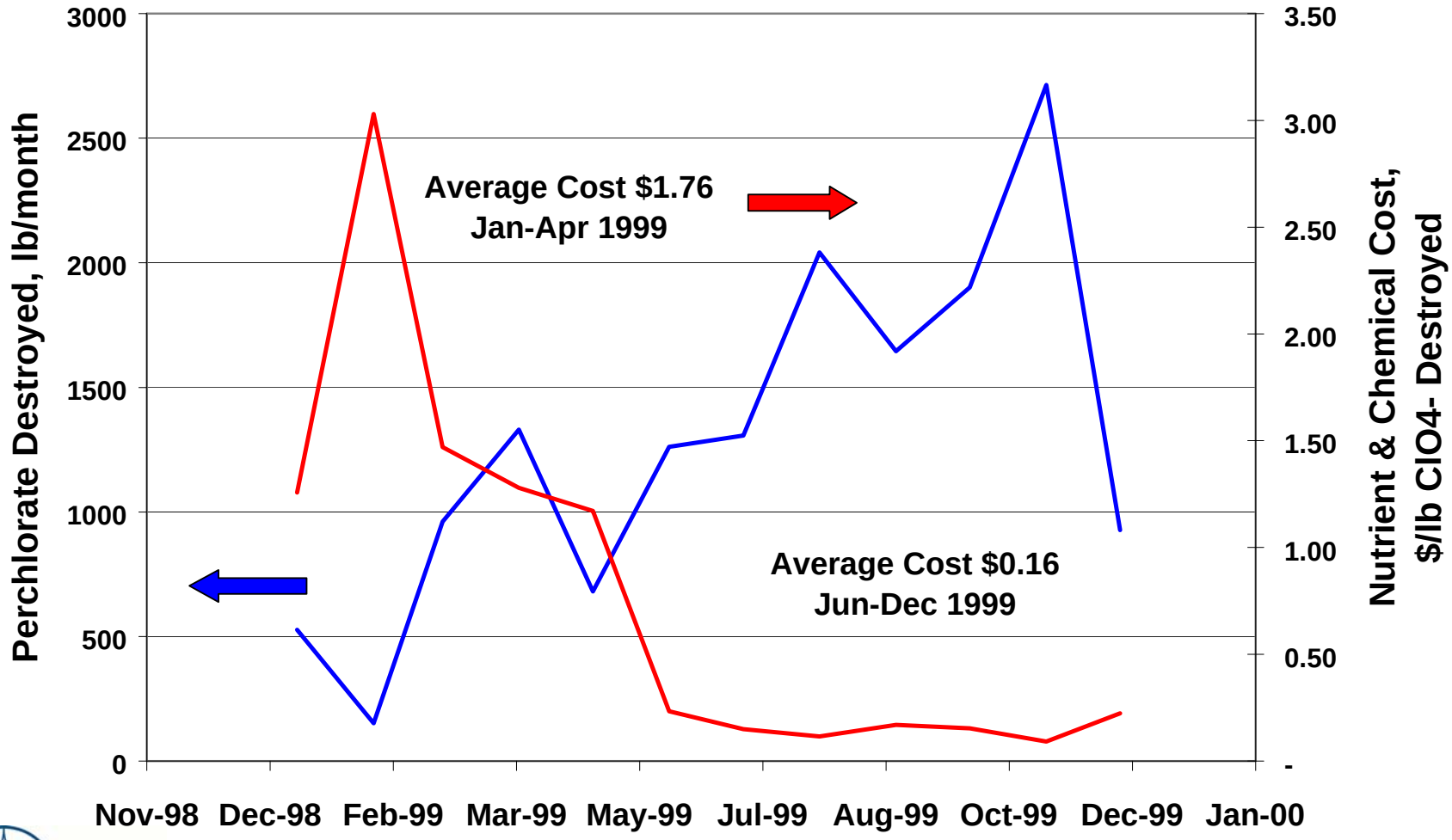
Prototype Performance for 1999



Fluctuations in Perchlorate Feed Concentration



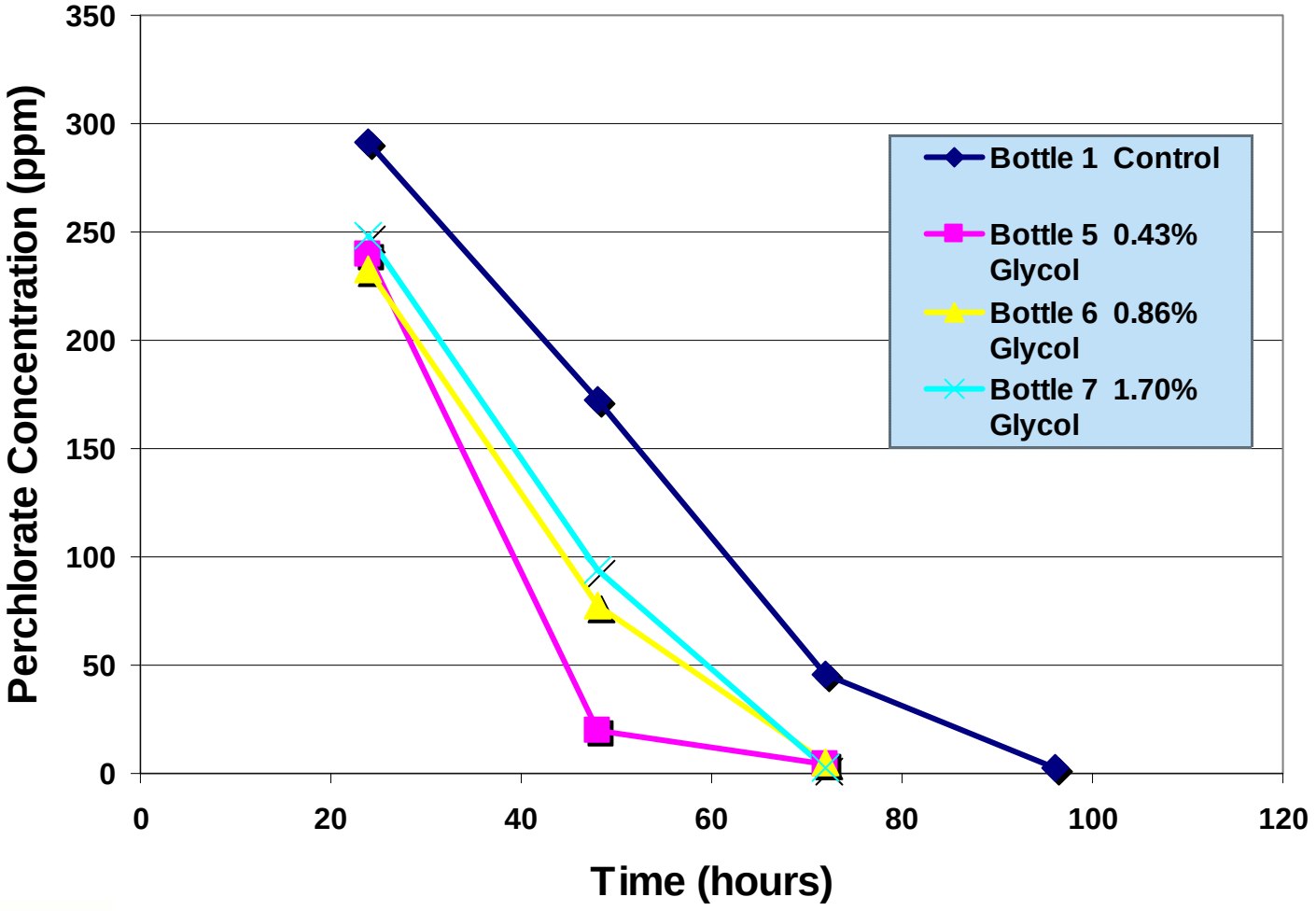
Summary of Nutrient and Chemical Cost



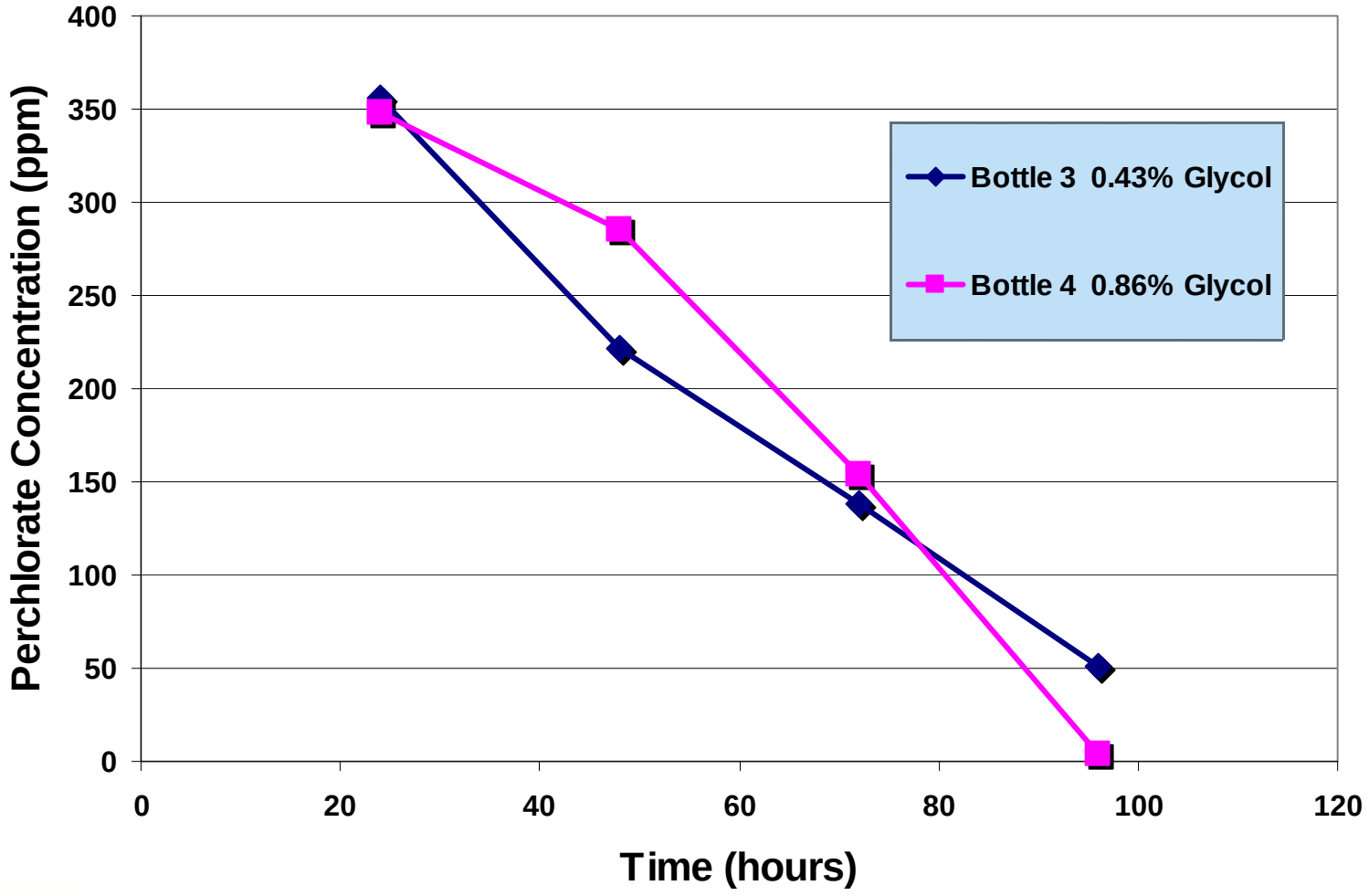
Alternate Effluents Evaluated

- **Objectives of Alternate Effluent Studies**
  - **Can Alternate Effluents be Co-processed with ClO_4^- ?**
    - **Determine Impact to Perchlorate Biodegradation**
    - **Determine Threshold Concentration**
  - **Determine Nutritional Contribution**
- **Bottle Tests were Performed**
  - **Ethylene Glycol Effluent**
  - **Isopropyl Alcohol (IPA) - From HMX Drying**
  - **Brulin Solution - Contaminated Aqueous Degreaser**

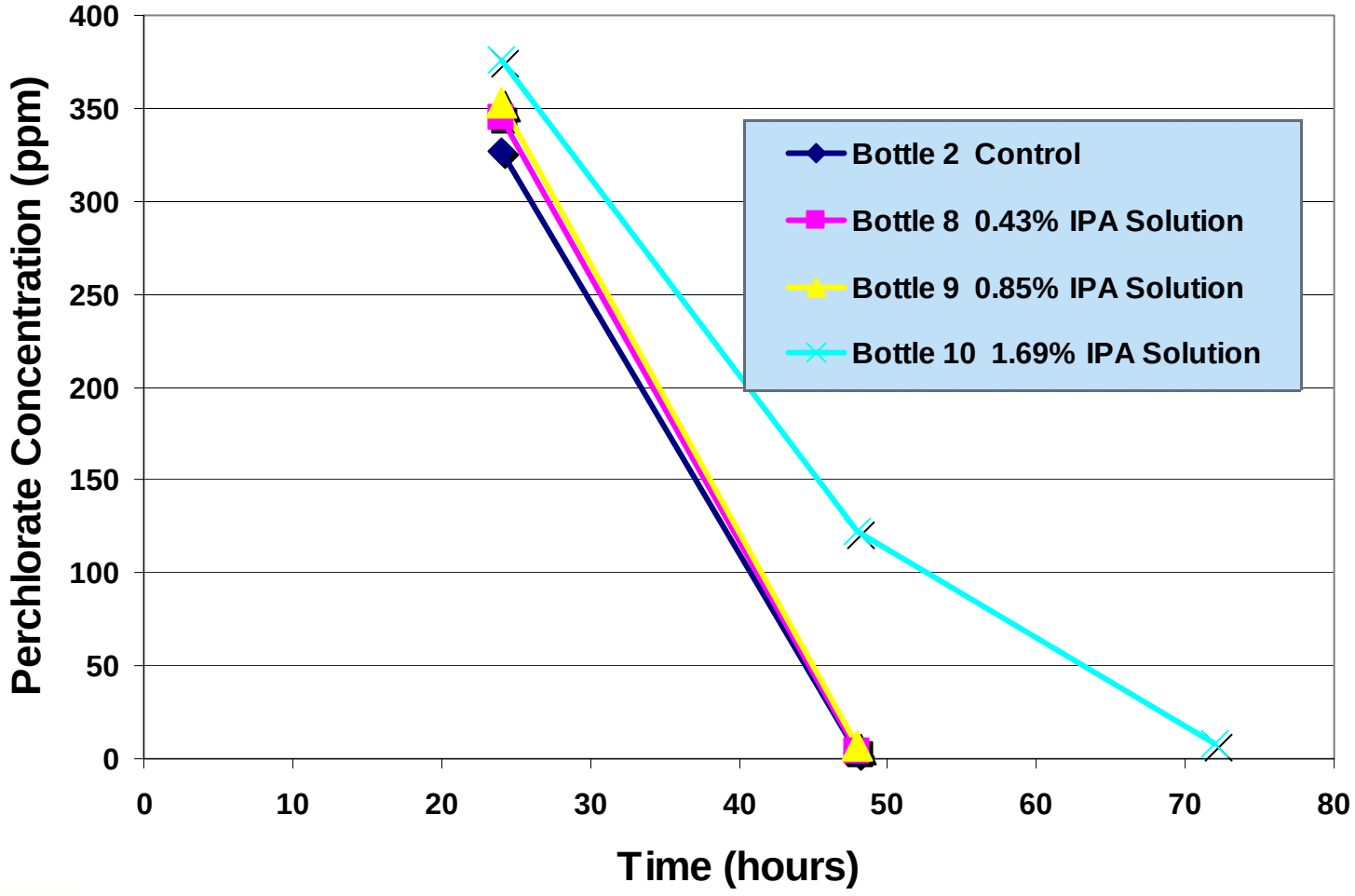
Glycol Bottle Test Results



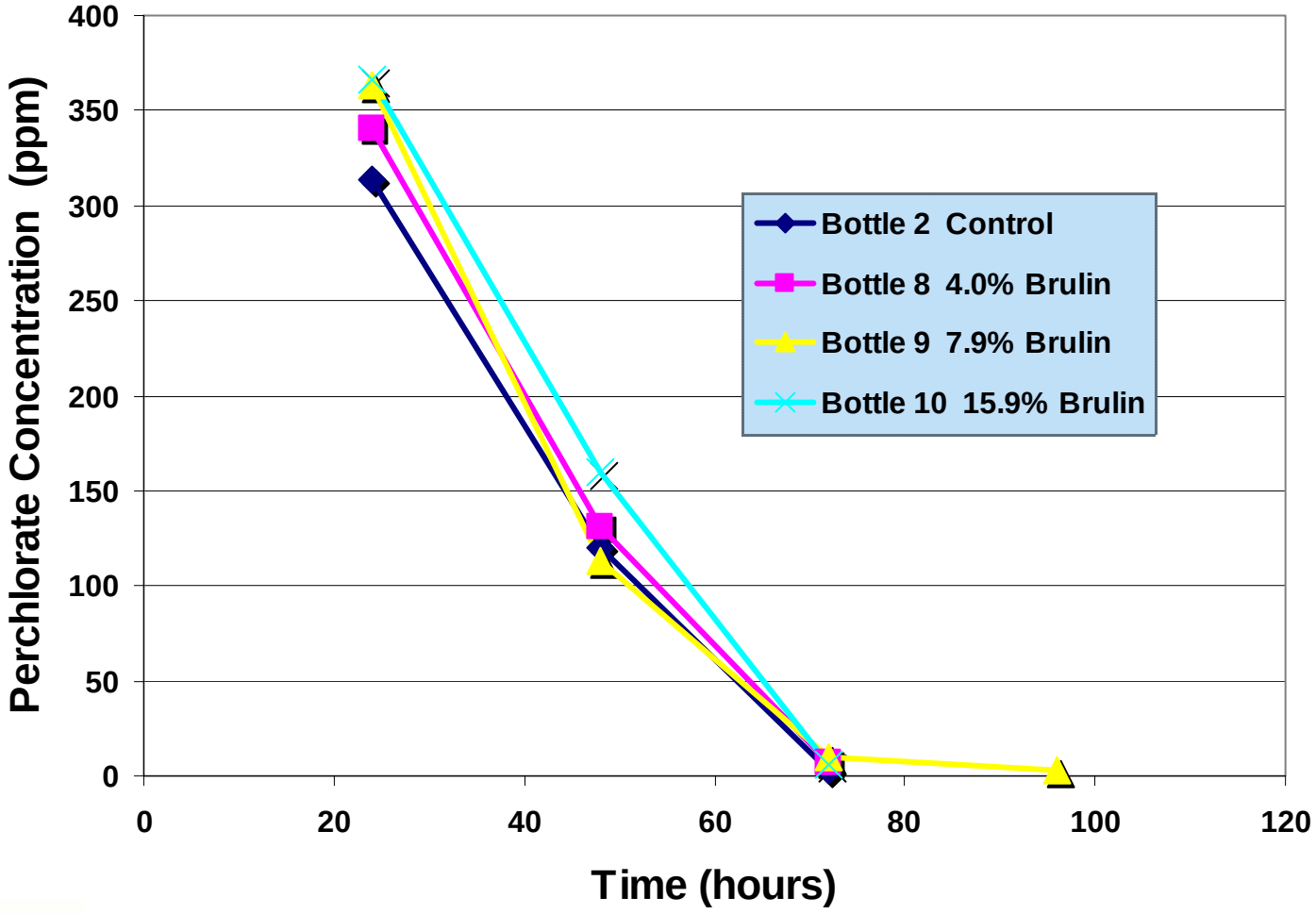
Glycol Bottle Test without CBP Nutrient



Isopropyl Alcohol Bottle Test Results



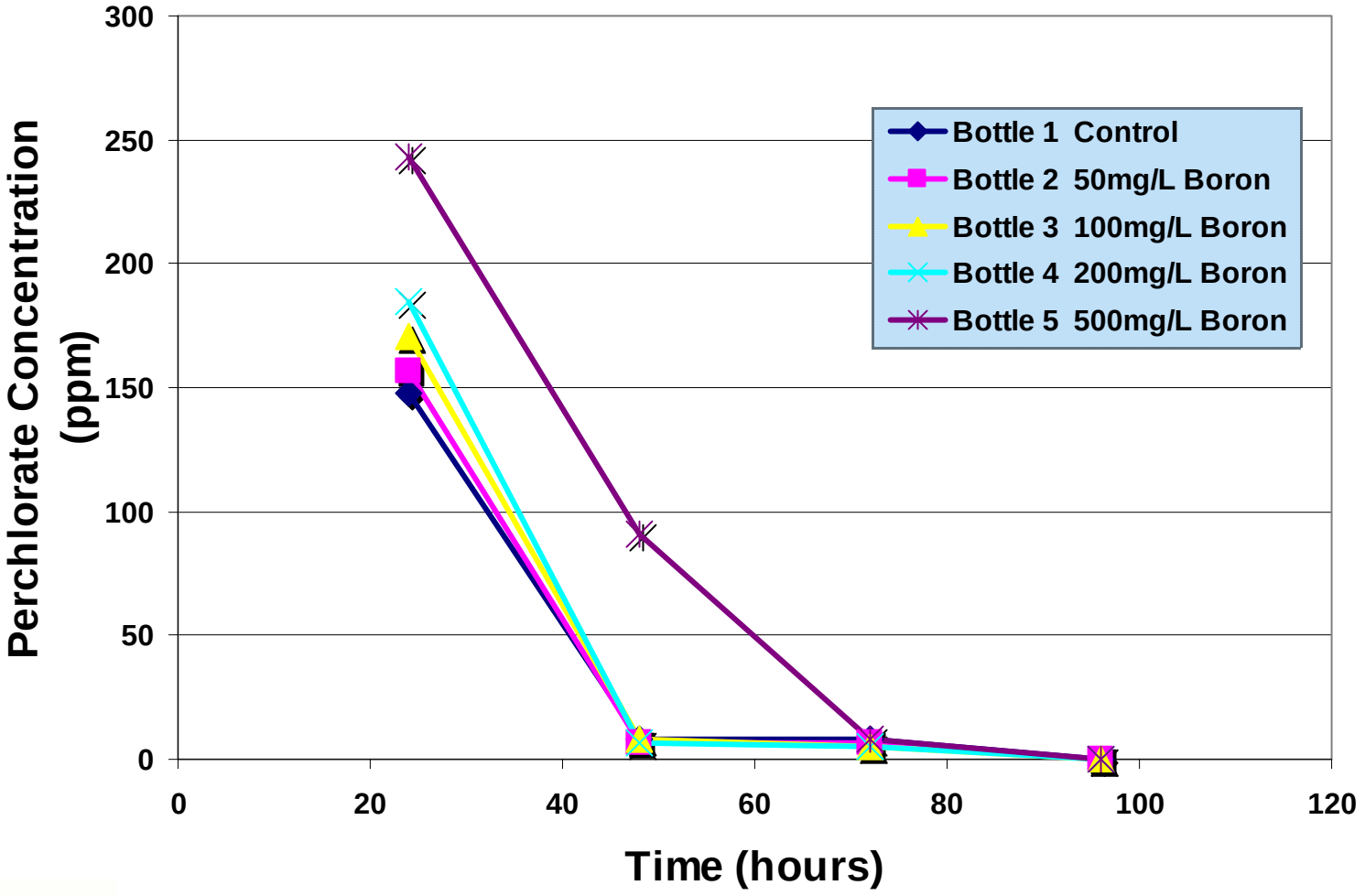
Brulin Bottle Tests Results



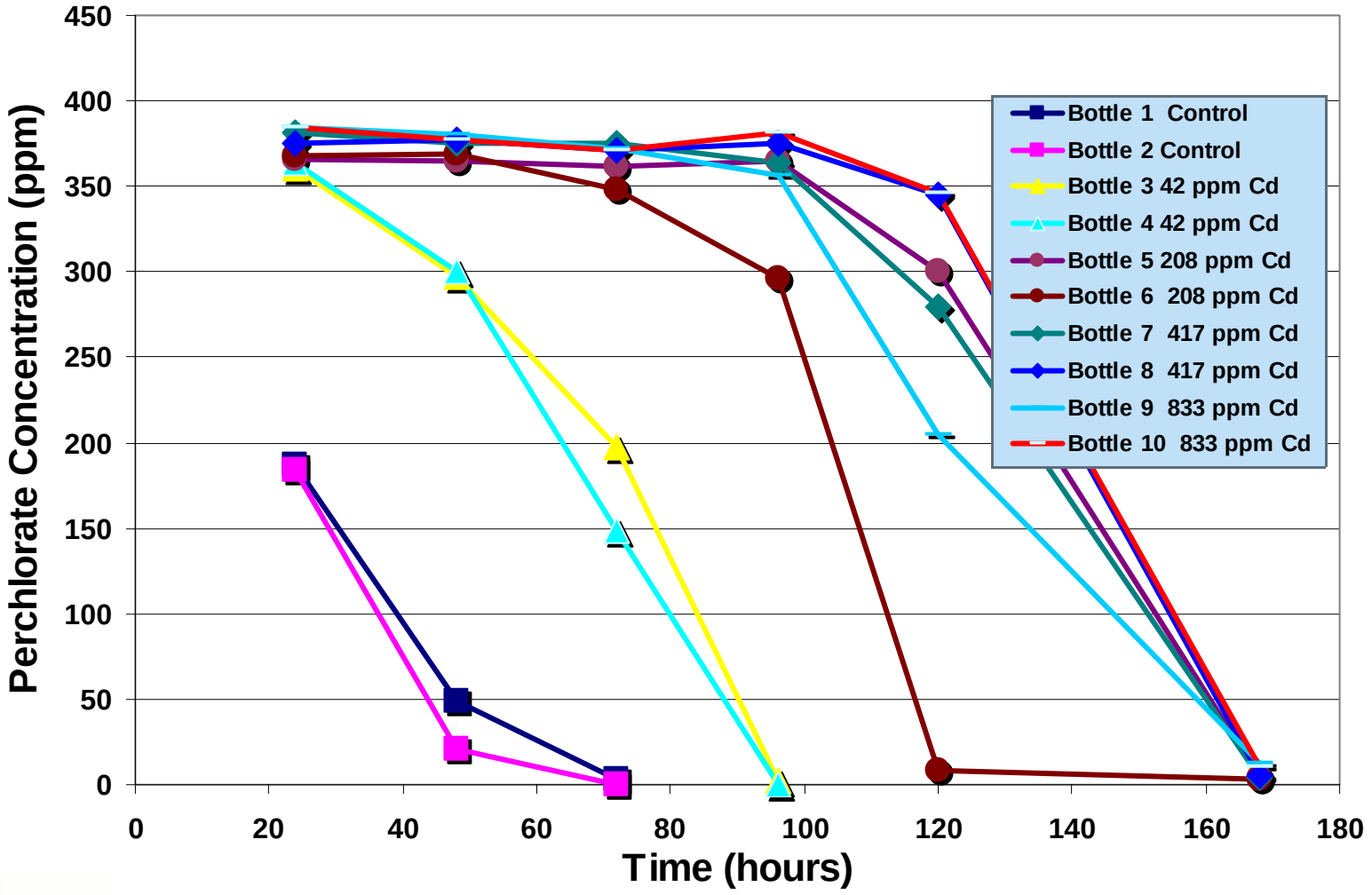
Co-Contaminant Evaluation

- **Boron**
  - **From Corrosion Inhibitors**
  - **Can Bio-accumulate**
- **Cadmium**
  - **From System Components**
- **Aluminum Hydroxide: $Al(OH)_4$-**
  - **From Base Hydrolysis of Aluminized Compositions**

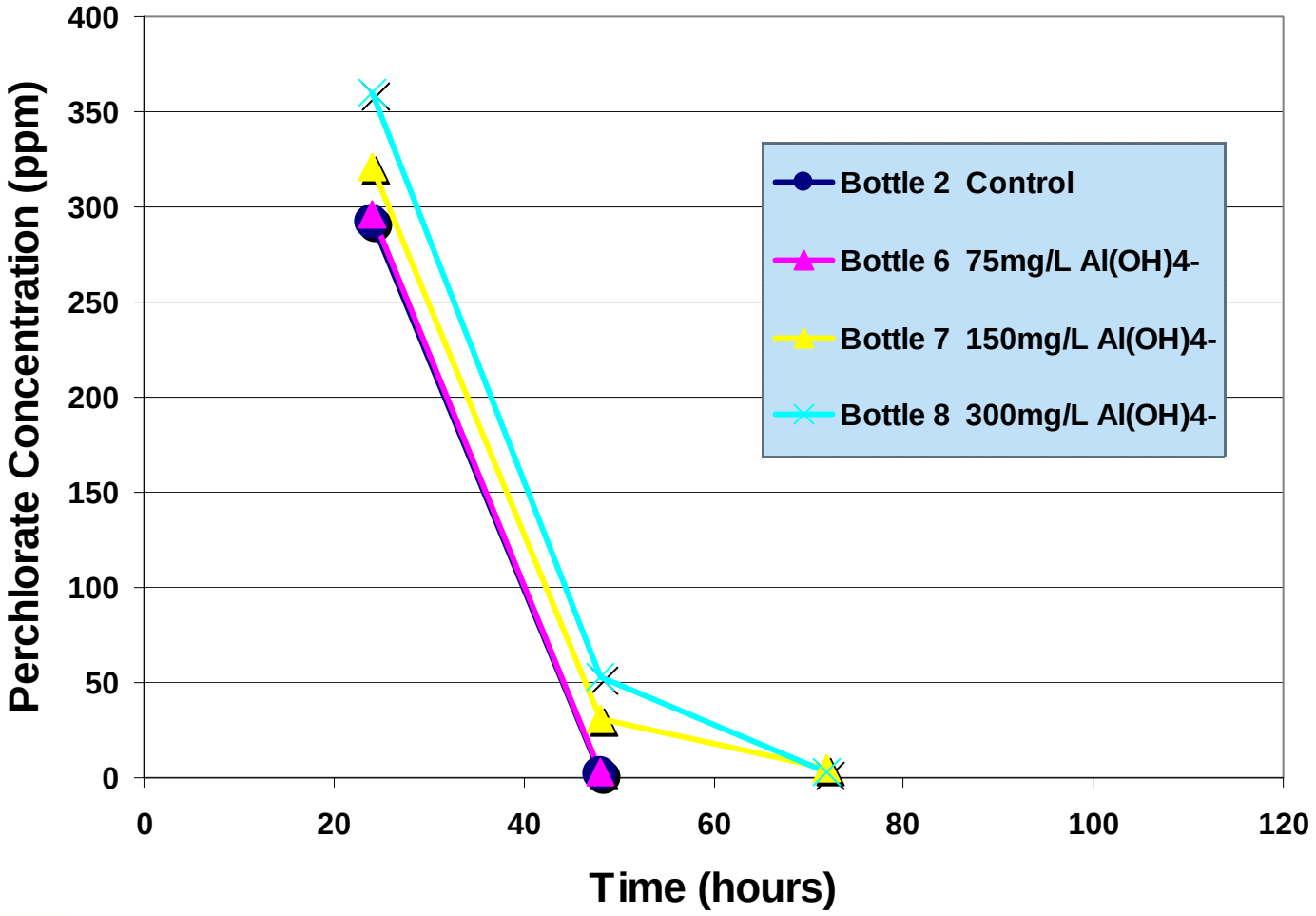
Boron Bottle Test Results



Cadmium Bottle Test Results



Aluminum Hydroxide Bottle Test Results



Prototype Modifications

- **Project approved to increase capacity**
  - **Production programs will increase effluent quantity**
  - **Ammonium and potassium perchlorate effluents**
  - **Initiate early Fall 2000**
- **Modifications will increase capacity 2 to 4-fold:**
  - **Multiple effluent feed systems**
  - **Higher capacity flow control valves**
  - **Optimize configuration for series operation**
  - **Upgrade nutrient feed systems and software**
  - **Upgrade effluent handling**

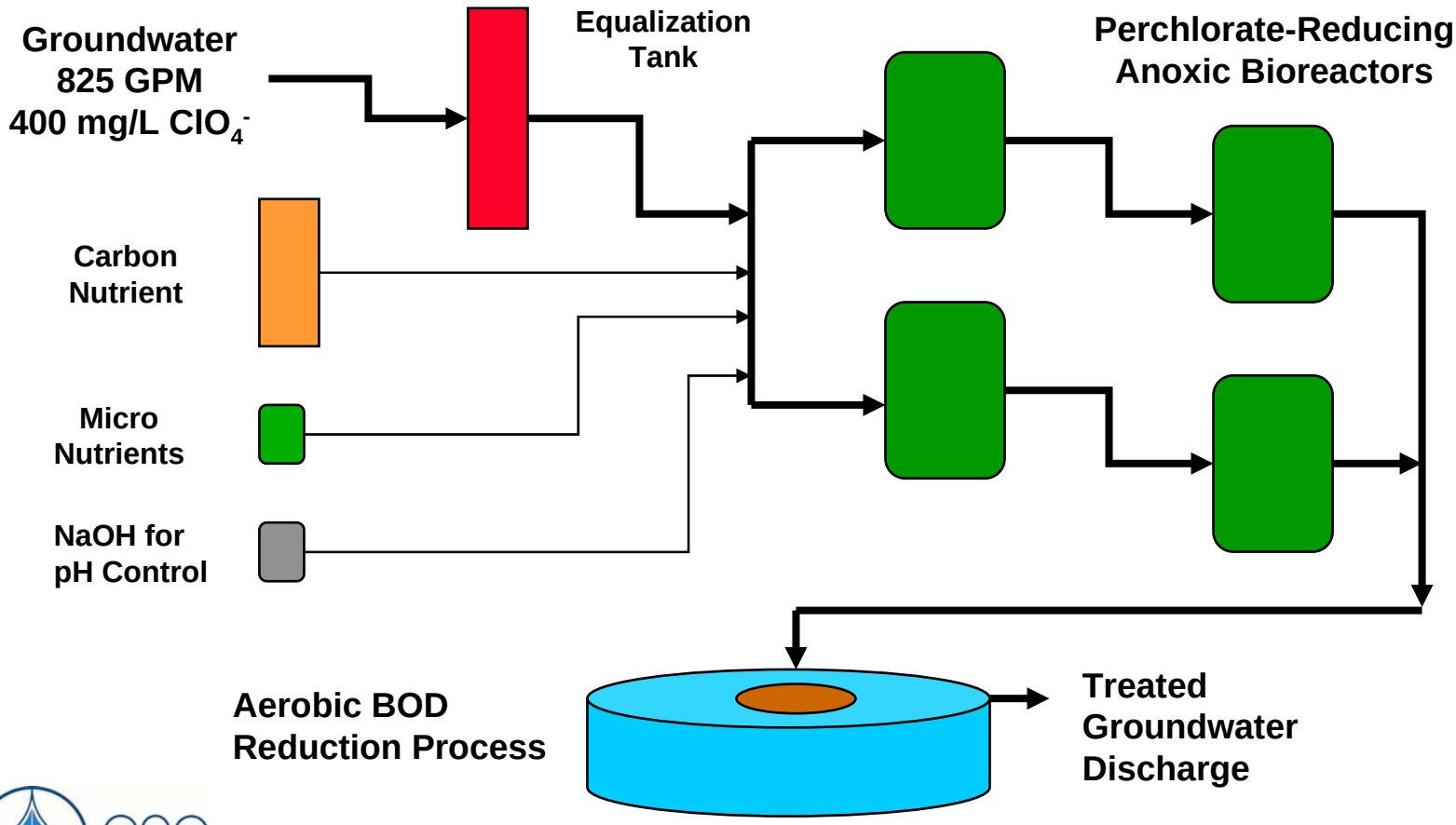
Full-Scale Treatment Plant

- **BMI Industrial Complex, Henderson, Nevada**
- **Design Basis**
  - **825 GPM (1.2 MGD) Highly Contaminated Groundwater**
  - **Nominal 400 mg/L Perchlorate Influent**
    - **4000 lb/day perchlorate removal and destruction**
  - **12,000 mg/L Total Dissolved Solids**
  - **Simultaneous Reduction of Nitrate and Chlorate**
  - **< 8-Hour Hydraulic Residence Time (HRT)**
  - **Meet NPDES Permit Requirements**
- **Engineering Design Nearly Complete**
  - **Teamed with Biothane Corporation for design/engineering**

Biodegradation of Perchlorate in Groundwater

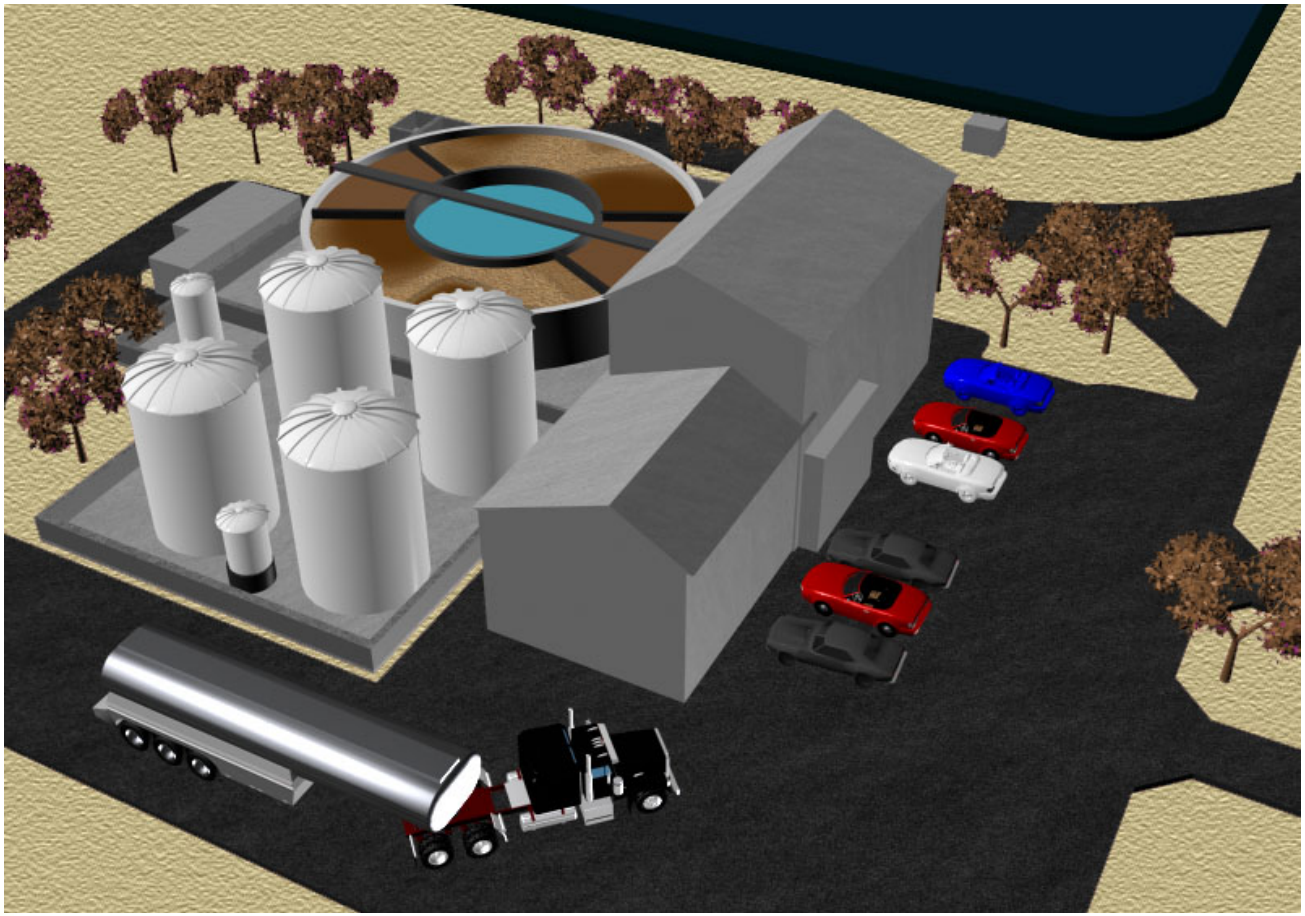
Process Flow Diagram for Kerr-McGee Chemical LLC, Henderson, NV

Applied Research Associates, Inc., Biothane Corporation, Smith & Loveless, Inc.



Groundwater Treatment Process

Henderson, Nevada



Thermal Treatment

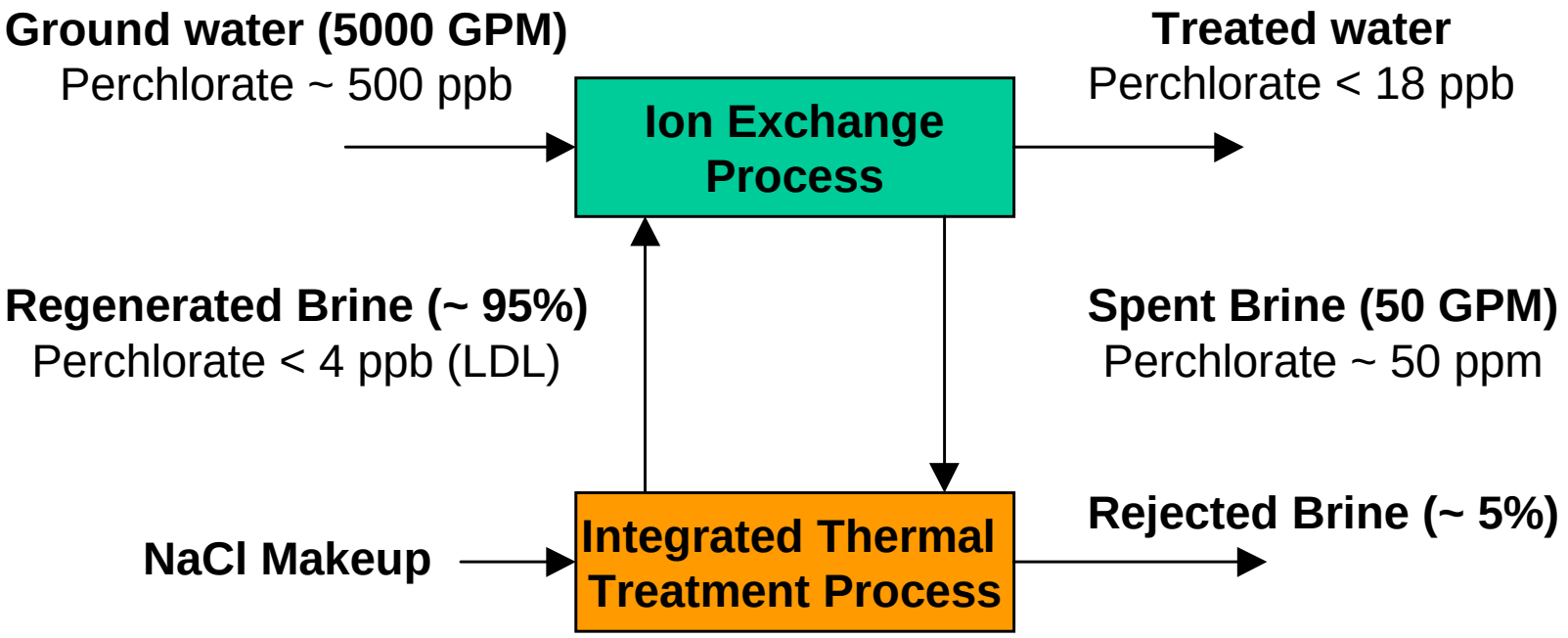
- EPA project to regenerate ion exchange brine
  - Thermal and hydrothermal approaches evaluated
- Surrogate brine was prepared for testing

Components	Concentration, mg/L
Water Softener Salt	7 wt%
Sodium Nitrate	800 (as NO_3-)
Sodium Sulfate	3000 (as SO_4=)
Sodium Bicarbonate	200 (as CO_3=)
Sodium Perchlorate	50 (as ClO_4-)

Hydrothermal Treatment

- High temperature, high pressure approach
- Non-catalytic process
  - With and without promoting/reducing agents
- Complete perchlorate reduction obtained
  - 340°C process temperature
  - High ferric chloride concentration required
- Partial perchlorate reduction obtained without promoting or reducing agents

Thermal Treatment Process



Thermal Treatment Process

- **Complete perchlorate reduction demonstrated**
  - **At 170°C with reducing/promoting agents**
  - **Below 600°C without reducing/promoting agents**
- **Sulfate removal demonstrated**
- **Preliminary process design developed**
  - **Commercial off-the-shelf equipment**
- **Economic evaluation showed 20-30% ROI possible**
  - **Based on $100/Kgal of brine disposal & replenishment**

Summary

- **Thiokol Prototype Optimization Results**
  - **90% Reduction in Nutrient and Chemical Cost**
  - **Potential to Co-Process Many Contaminants/Effluents**
  - **2-4 Fold Improvement in Performance Possible**
- **ARA Completed Designs for Largest Perchlorate Groundwater Treatment Process**
- **ARA Issued a New Patent, “Biodegradation of Ammonium Perchlorate, Nitrate, Hydrolysates and Other Energetic Materials”**
- **ARA Developed Economical Thermal Treatment Processes for Ion Exchange Brines**