SLOVAK ENVIRONMENT AGENCY

is implementing an activity

INTERNATIONAL CONFERENCE

CONTAMINATED SITES

ZNEČISTENÉ ÚZEMIA

MEDZINÁRODNÁ KONFERENCIA

INTERNATIONAL CONFERENCE

CONTAMINATED SITES 2022

SENEC, SLOVAK REPUBLIC, 12 – 14 OCTOBER 2022

The activity has been implemented within the framework of national project
***Information and providing advice on improving the quality of environment in Slovakia**.*
The project is cofinanced by Cohesion Fund of the EU under Operational programme Quality of Environment.

www.op.kzp.sk *www.minzp.sk* *www.sazp.sk*

Enhanced Bioremediation of Soil Using Sustainable Soil Amendments

Alan Seech, Ph.D.
Soil & Groundwater Remediation
Evonik Active Oxygens, LLC
Corona Del Mar, California
Alan.Seech@evonik.com
Cell: +1-949-514-1068

The activity has been implemented within the framework of national project
Information and providing advice on improving the quality of environment in Slovakia.
The project is cofinanced by Cohesion Fund of the EU under Operational programme Quality of Environment.

OP KŽP
European Union
Cohesion Fund
MINISTRY OF ENVIRONMENT OF THE SLOVAK REPUBLIC
SLOVAK ENVIRONMENT AGENCY

Agenda

1. **Problem Definition and Approach to Remediation**
2. **Composition of Terramend® and Daramend® Reagents**
2. **Completed Large-scale Applications Terramend® and Daramend®**
3. **Contaminant Destruction Mechanisms: Microbial, Chemical, and Biochemical**
4. **Laboratory Testing Data** (Lindane, TNT, Petroleum Hydrocarbons)
5. **Project Snapshots**
   - ✓ Pentachlorophenol, PAHs, & Petroleum Hydrocarbons in Soil (Ontario, Canada)
   - ✓ Toxaphene & DDT (California, USA)
   - ✓ TNT & RDX in Sediment (US Navy Site, Virginia, USA)
6. **Comments, Questions, and Answers**

Problem Definition

1. Many contaminants have high acute toxicity, low water solubility, and long half-lives in soil (HMW hydrocarbons, many PAHs, chlorinated pesticides).
2. Traditional bioremediation methods (i.e., addition of fertilizer, composting, inoculation with “special” bacteria) have been ineffective for these compounds.
3. Remedial standards can be stringent, and attainment of residential standards is often required because the most common land use change is from agricultural or industrial to residential.
4. Impacted areas can be very large, making off-site disposal prohibitively expensive. Transportation and landfill disposal is not a sustainable approach.

Proven Applications

Contaminants Treated	Reagent	Treatment Method
Petroleum Hydrocarbons	Terramend®	Aerobic
PAHs, Chlorinated Phenols, Phthalates	Terramend®	Aerobic
Lindane and other BHCs	Terramend® or Daramend®	Aerobic or Anaerobic
2,4-D, 2,4,5-T, Metolachlor	Daramend®	Anaerobic
DDT, Dieldrin, Chlordane, other chlorinated pesticides	Daramend®	Anaerobic
TNT, RDX, HMX, Tetryl	Daramend®	Anaerobic

Composition of Terramend® and Daramend® Soil Amendments

Attribute	Terramend® Carbon	Terramend® Inorganic	Daramend®	Daramend® Plus	Benefits
High Surface Area Hydrophilic Plant Fiber	✓	✓	✓	✓	↑ Soil WHC, New non-toxic surface area
Slow-release Organic Carbon & Nutrients (N, P, S)	✓	✓	-	-	Feed bacteria without inhibition of fungi
Rapid-release Organic Carbon & Nutrients (N, P, S)	-	-	✓	✓	Quick creation of strong reducing conditions
Inorganic Nitrogen & Phosphorus	-	✓	-	-	Achieve desired C:N:P ratio in soil with high TPH
Emulsifying Agent	✓	✓	✓	✓	Increase bioavailability of contaminants
pH Balanced	✓	✓	✓	✓	Prevent negative ΔpH
Microscale ZVI (Fe^0)			✓	✓	Chemical reduction
Activated Carbon				✓	Physical adsorption

Applications

In Situ Treatment of PCP and PAHs in Surface Soil, 0-60 cm bgs (Industrial Site)

Applications

In-Situ Treatment of DDT and Dieldrin in Soil (34-acre Agricultural Site)

Applications

Ex-Situ Treatment of Pentachlorophenol (Chemical Production Site)

Applications

Ex-Situ Treatment of Organic Explosive Compounds (US Army Ammunition Plant)

Applications

Ex-Situ Soil Treatment of TNT and RDX in Windrows (US Army Site near Chicago IL)

Applications

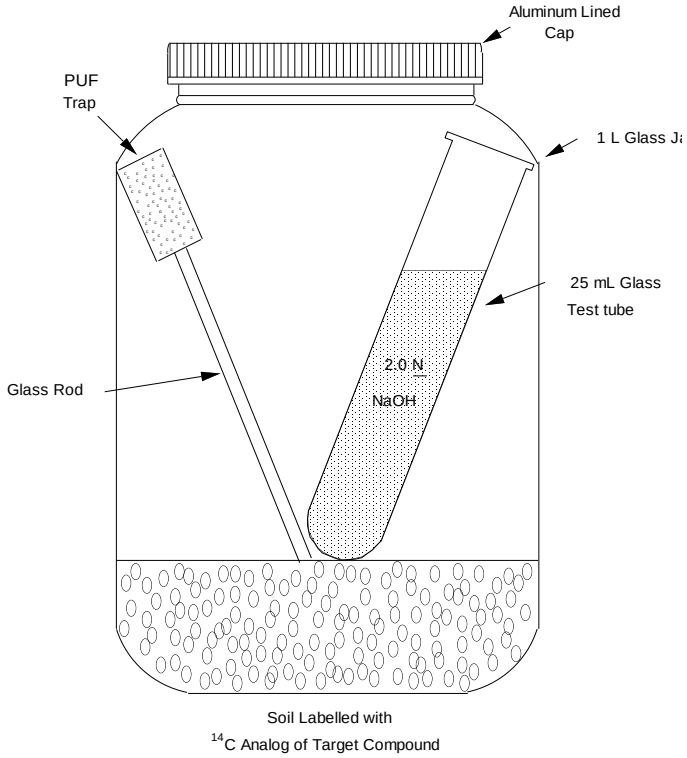
In-Place Pretreatment of TNT and RDX in Sediment (0 – 2.5 m bgs, US Navy Site, Yorktown VA)

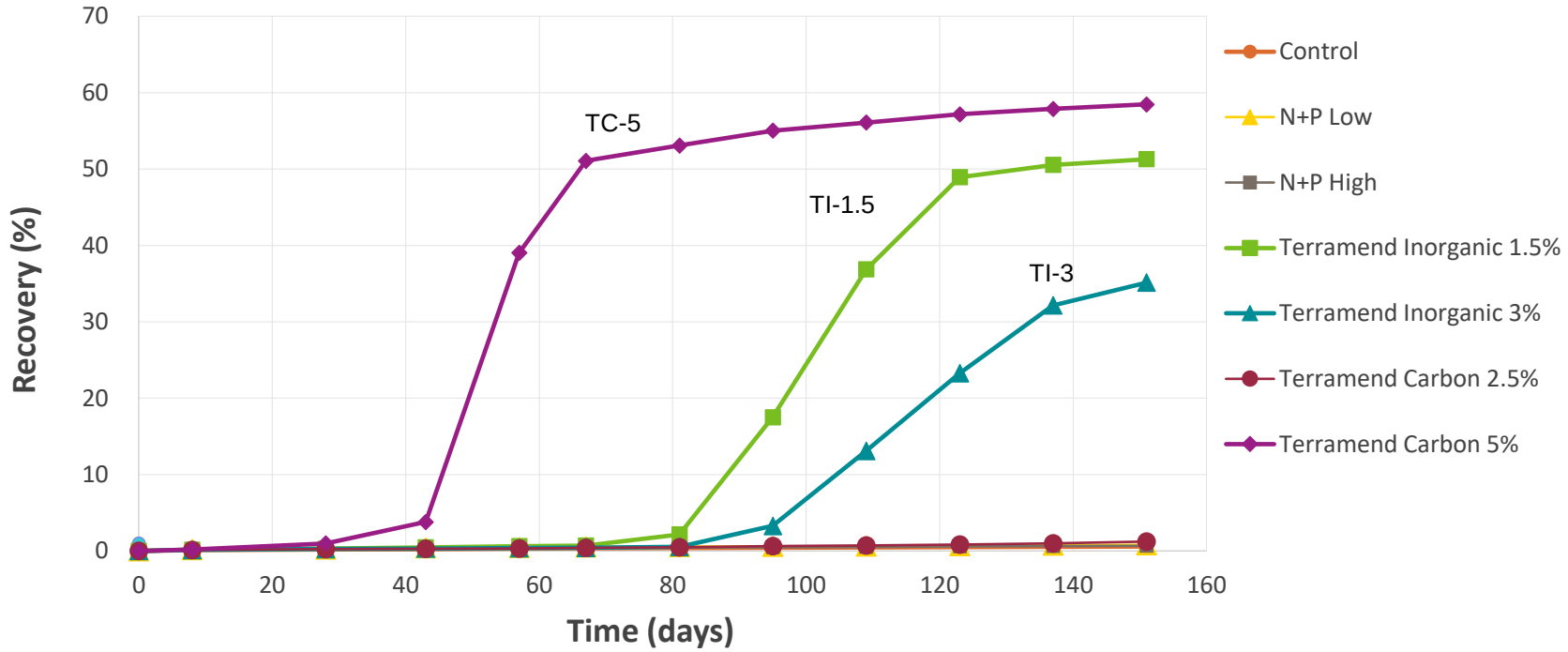
Bench-scale Laboratory Treatability Testing

1. Objective: Confirm soil can be treated to the required extent.
2. Benefit: Confirm most effective soil amendment(s).
3. Benefit: Estimate required amendment dosage.
4. Benefit: Estimate treatment time.
5. Result: Go to full-scale application with understanding of time required and cost to complete soil treatment.

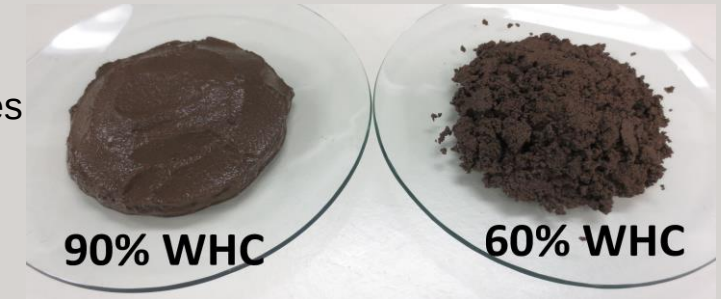
Bench-scale Treatability Testing to Confirm Biodegradation of PCP in Soil

Complete Biodegradation of ^{14}C-Pentachlorophenol to ^{14}C-CO_2





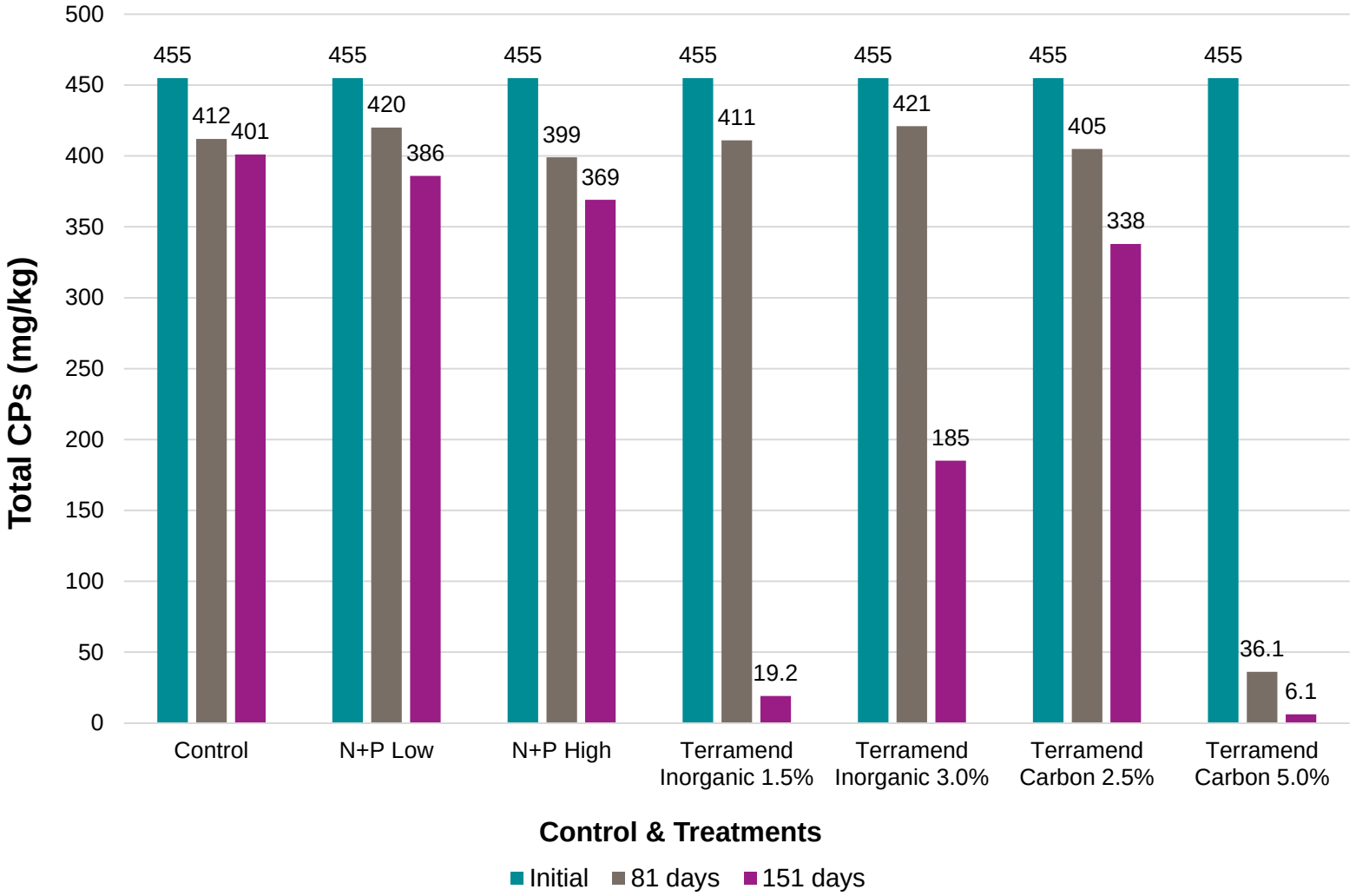
- Documents complete biodegradation of PCP
- Compares performance of reagents & dosages
- Supported by traditional extraction & GC analysis



- Terramend® Carbon at 5% w/w performed best
- Order of performance same as increase in soil WHC
- Hydrophobic soil with acutely toxic COI
- Poor response to both N+P nutrient treatments

EVONIK Leading Beyond Chemistry

Bench-scale Treatability Testing for PCP in Soil
Total Extractable Chlorinated Phenols

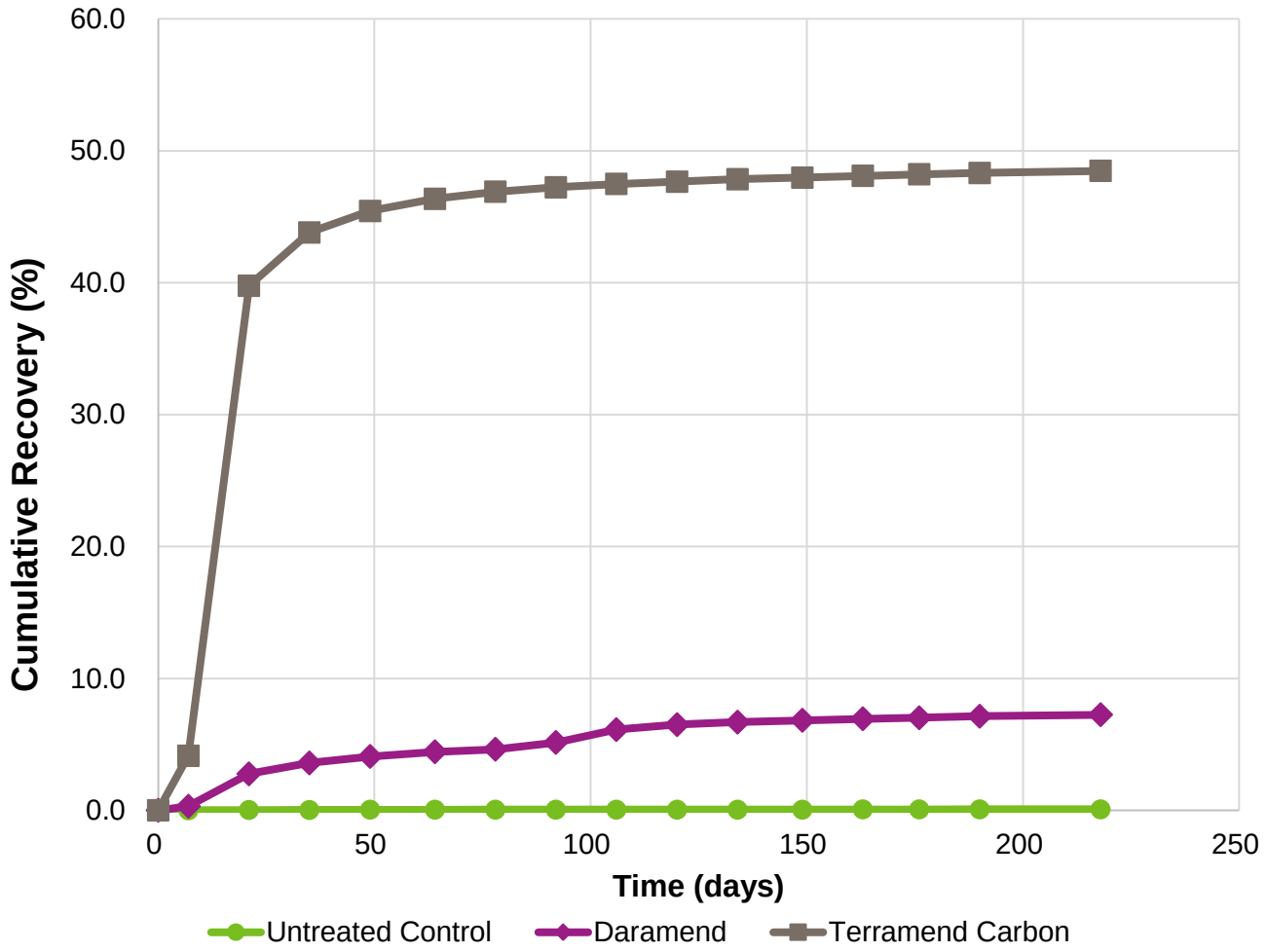


- ✓ Very good agreement between mineralization of ^{14}C-PCP and reduction in total extractable CPs
- ✓ Treatments that supported greatest conversion of radiolabeled PCP to CO_2 also achieved lowest residual CP concentrations
- ✓ Higher dose of slowly-released Terramend Carbon provided large increase in soil WHC without turning soil anaerobic
- ✓ More rapidly-released Terramend Inorganic at the higher dose may have resulted in less oxic conditions in this soil
- ✓ Inorganic N+P was ineffective regardless of dosage

EVONIK Leading Beyond Chemistry

Bench-scale Treatability Testing for Lindane in Soil

Complete Biodegradation of of ^{14}C-Lindane to ^{14}C-CO_2

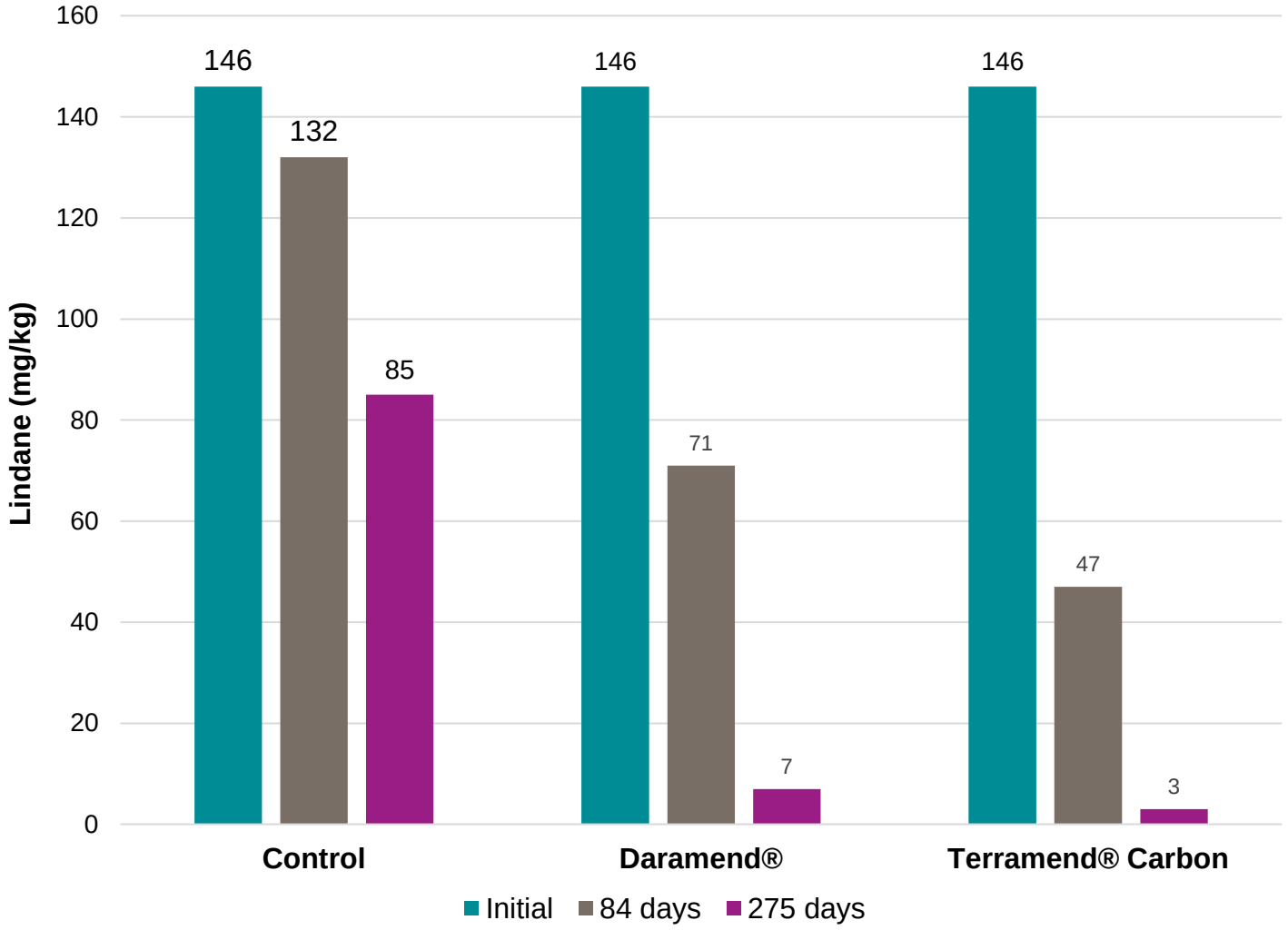


Radioisotope Fate Study

- Industrial soil from Lindane manufacturing site
- Tracked conversion of ^{14}C-γ-hexachlorocyclohexane (Lindane) to ^{14}C-CO_2 in glass microcosms
- Compared untreated control to soil amended with Terramend® Carbon (3.0%) or Daramend® (4.0%)
- Literature says half life of Lindane should be shorter under anaerobic conditions
- Our results differed as we found more rapid and more substantial biodegradation of Lindane under optimized aerobic conditions than under highly reduced anaerobic conditions (ORP = -450 mV)

EVONIK Leading Beyond Chemistry

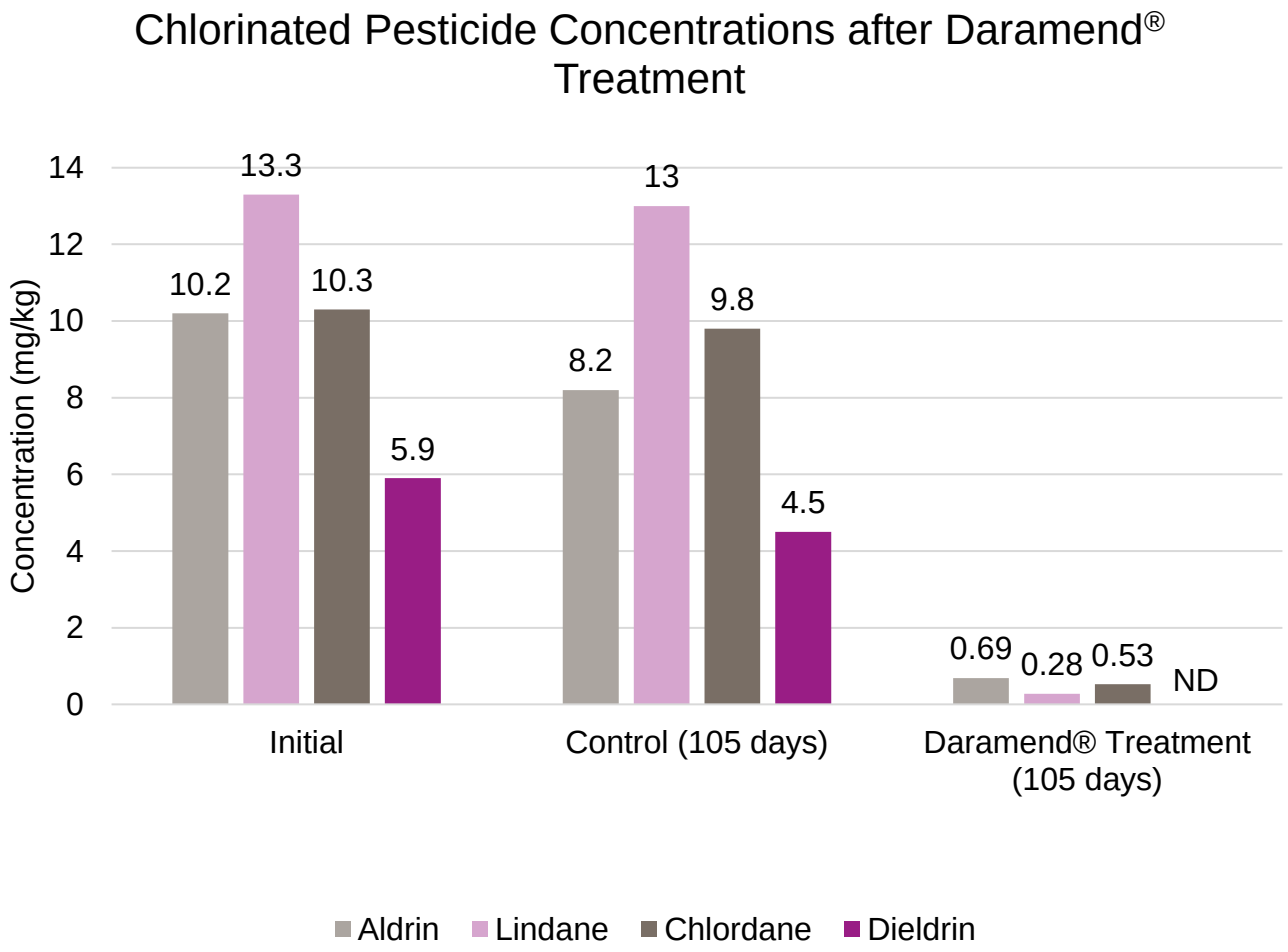
Bench-scale Treatability Testing for Lindane in Soil
Influence of Soil Treatment on Total Extractable Lindane



- Total extractable Lindane by EPA 3540 and 8081B
- Total extractable Lindane was in good agreement with results from mineralization of added ^{14}C-Lindane to CO_2
- Both reductive dechlorination (Daramend®) and aerobic bioremediation (Terramend® Carbon) were effective in degradation of Lindane in this soil
- Isolates of *Sphingomonas japonicum* and several other bacteria have been shown to use Lindane as sole source of carbon and energy through aerobic dechlorination and hydroxylation and ring cleavage
- Extracellular enzymes produced by soil fungi have also been shown to degrade Lindane

EVONIK Leading Beyond Chemistry

Daramend® Bench Scale Results:
Influence on Aldrin, Lindane, Chlordane, and Dieldrin concentrations in soil



Aldrin, Lindane, Chlordane, and Dieldrin are some of the most recalcitrant chlorinated pesticides. Still, in most soils, they are well treated with Daramend® reagent. In this case we applied seven treatment cycles over 105 days (0.5% w/w per cycle)

EVONIK Leading Beyond Chemistry

Project Snapshots

1. In-Situ/Ex-Situ Daramend® Treatment of Pesticides in Soil & Sediment, Superfund Site, Montgomery AL
2. In-Situ Daramend® Treatment of Toxaphene and DDT, Industrial site, Imperial Valley CA
3. In-Situ Daramend® Treatment of Chlordane, Agricultural Site, Palm Beach County FL
4. Ex-Situ Daramend® Treatment of TNT, US Navy Site, Yorktown VA

Project Snapshot 1

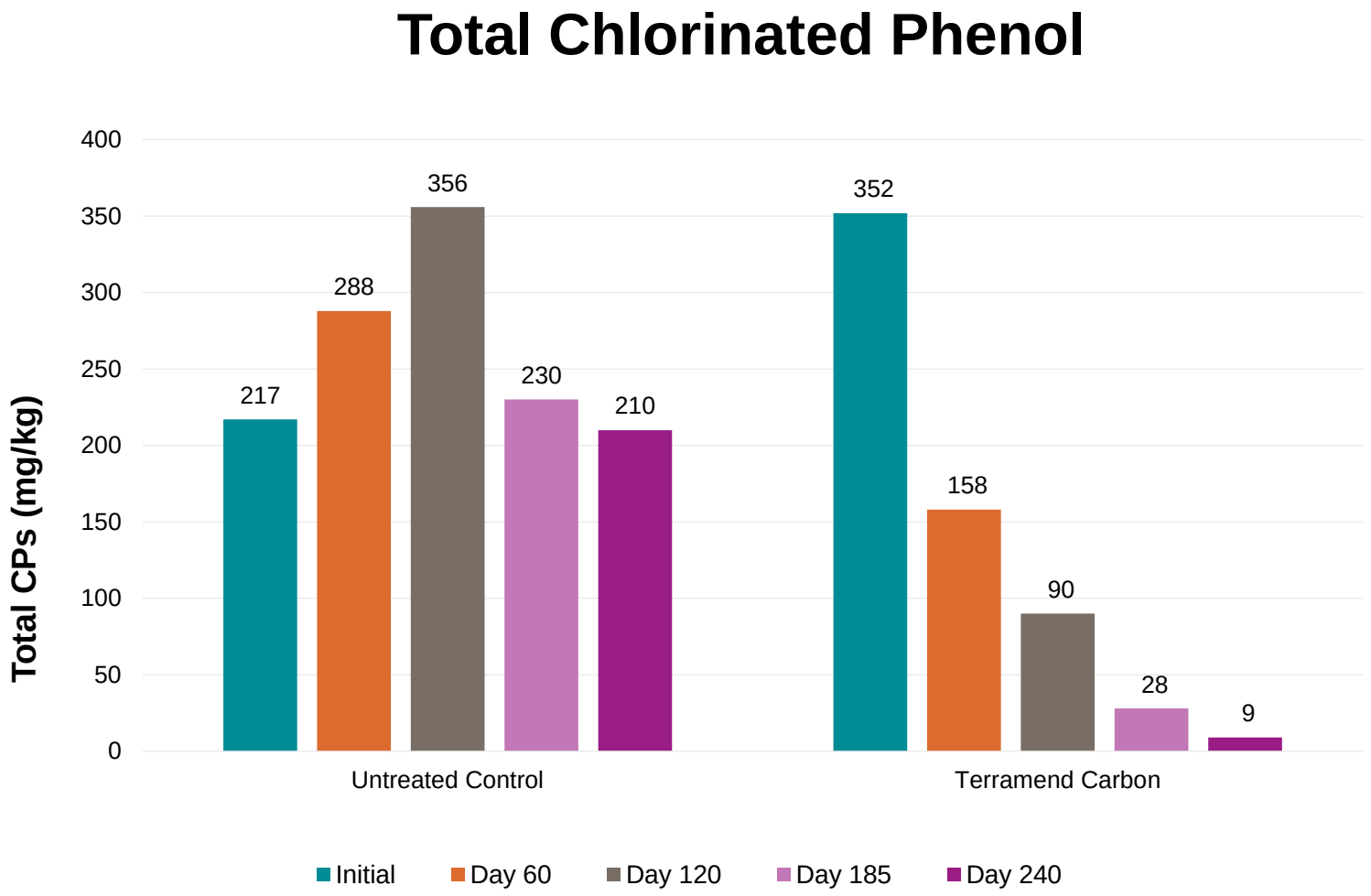
Terramend® Carbon

Ex Situ and In Situ Treatment of PAHs, Chlorinated Phenols, and Petroleum Hydrocarbons

- Industrial Wood Preserving Site
- Used creosote and pentachlorophenol in mineral oil to treat railroad ties and utility poles since 1950
- On-site treatment of excavated soil in HDPE-lined cell
- 1,200 tons/year in batch system
- In-situ treatment of 4,100 m^3 surface soil (0 – 60 cm bgs)

EVONIK
Leading Beyond Chemistry

Ex Situ Bioremediation of Wood Treatment Soil with Terramend® Carbon

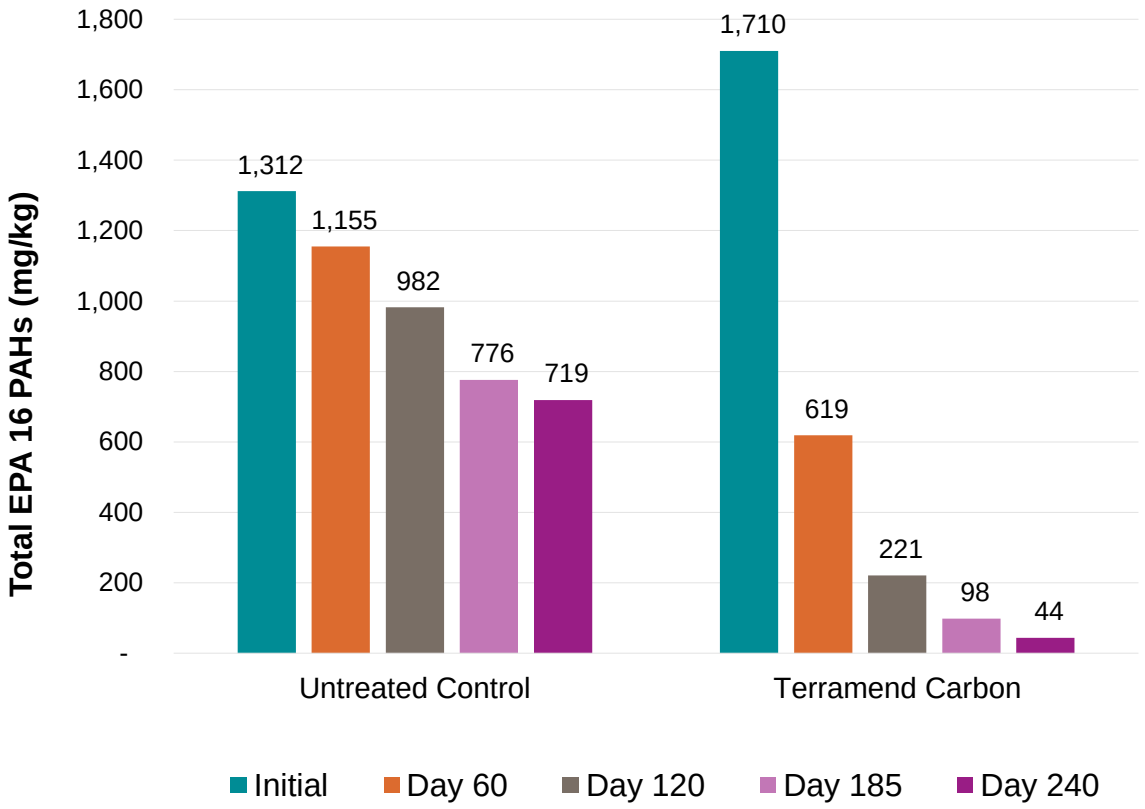


- Industrial wood preserving site in operation since 1950
- Pressure treatment using creosote and PCP in mineral oil
- Batch treatment of 1,200 tons/year over three years
- Excavated soil in HDPE-lined bioremediation cell
- Covered to extend treatment season in cool climate area
- First batch included monitoring of untreated control soil simultaneous with Terramend Carbon treated soil
- Also treated 4,800 tons of lightly impacted soil in-situ (0 – 60 cm bgs)

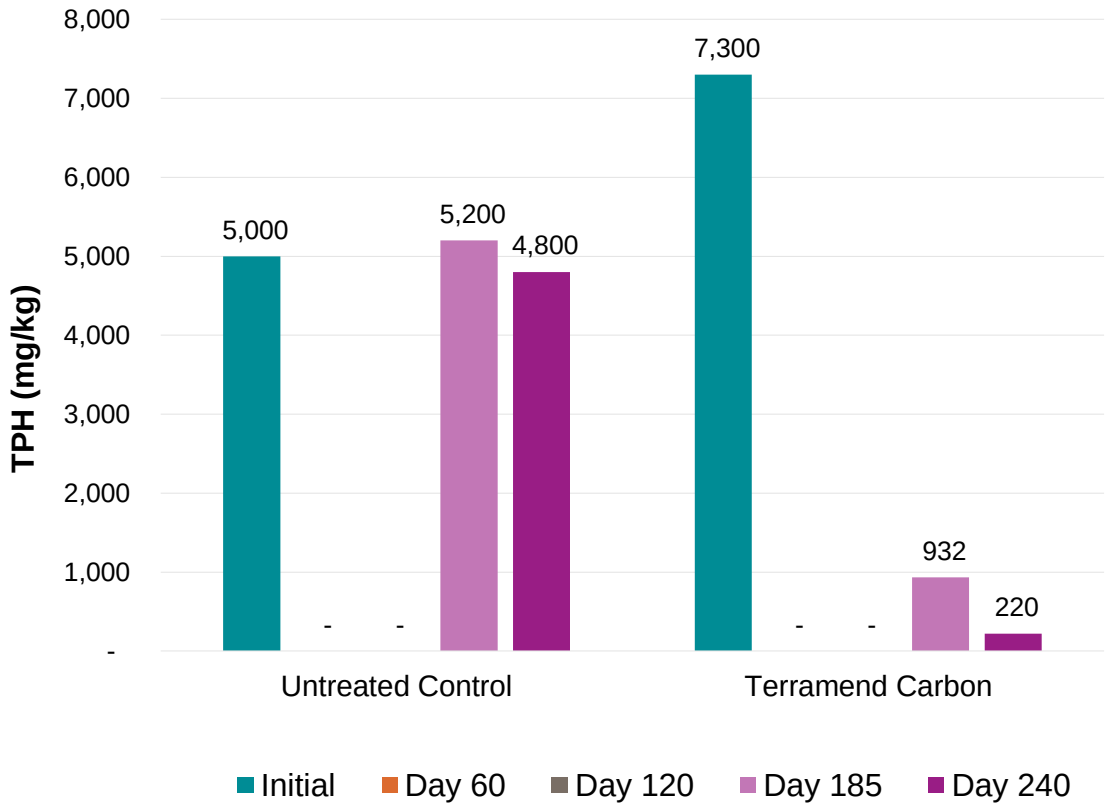
EVONIK Leading Beyond Chemistry

Terramend® Treatment of PAHs and Petroleum Hydrocarbons

Total PAHs



Total Petroleum Hydrocarbons



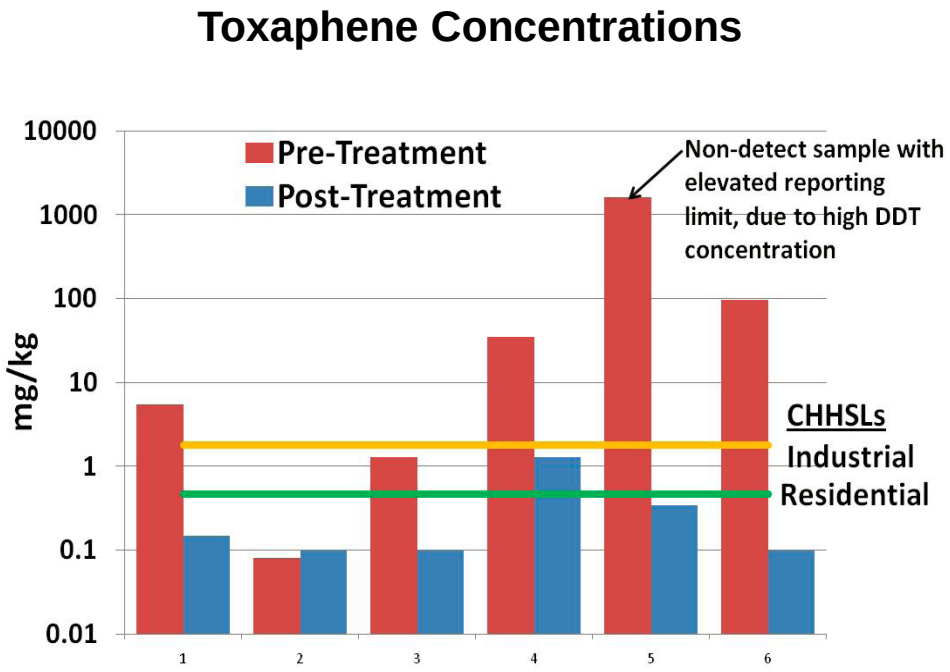
EVONIK
Leading Beyond Chemistry

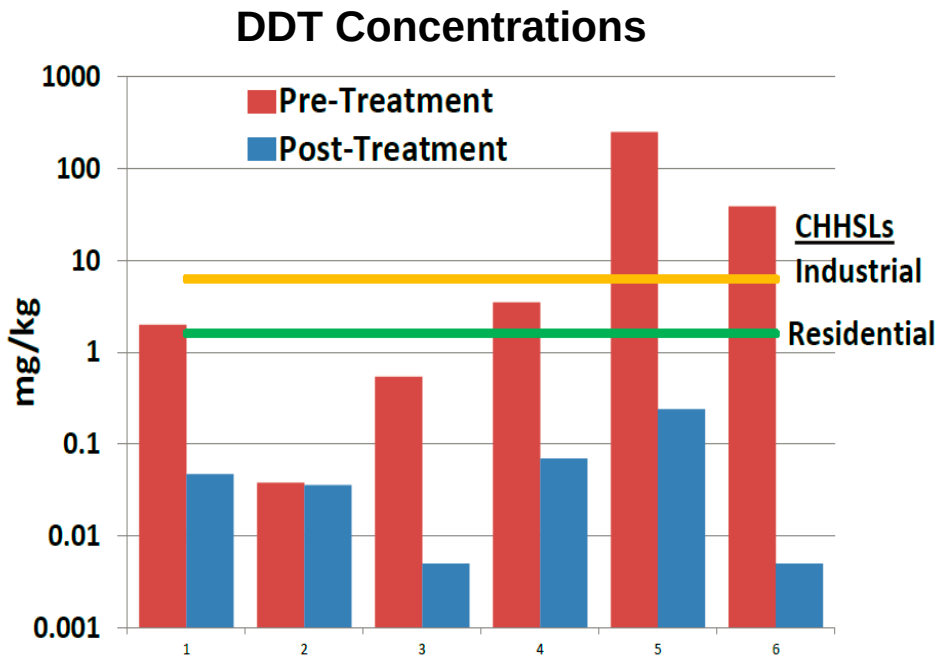
Project Snapshot 2:

In Situ Daramend® Treatment of Toxaphene and DDT
Industrial site in
El Centro California (180 km East of San Diego)

EVONIK
Leading Beyond Chemistry

Project Snapshot 2: Industrial site in Imperial Valley, CA
Performance Data for Toxaphene and DDT





- Industrial treatment standards achieved in all sampling zones after only one treatment cycle.
- Residential treatment standards achieved with only one treatment cycle for all but one sampling zone.
- High removal efficiencies and low residuals achieved for both DDT and Toxaphene.
- Presence of elemental sulfur seems to enhance removal with similar observation at another site with high elemental S.

EVONIK
Leading Beyond Chemistry

Project Snapshot 3:

Organic Explosive Compounds in Excavated Sediment

Naval Weapons Station Yorktown Yorktown VA

- ✓ 12,000 tons of soil treated in seven batches
- ✓ TNT concentrations as high as 43,000 mg/kg with an average concentration of about 10,000 mg/kg
- ✓ Treatment standards were 14 mg/kg for TNT
- ✓ Ex Situ Treatment of soil and sediment (impacted by effluent from washout of TNT manufacturing plant)
- ✓ Engineered Biocell, covered to prevent flooding and allow extended treatment season

EVONIK
Leading Beyond Chemistry

Project Snapshot 3: NWS Yorktown

TNT Concentrations in Yorktown Soil after Daramend® Treatment

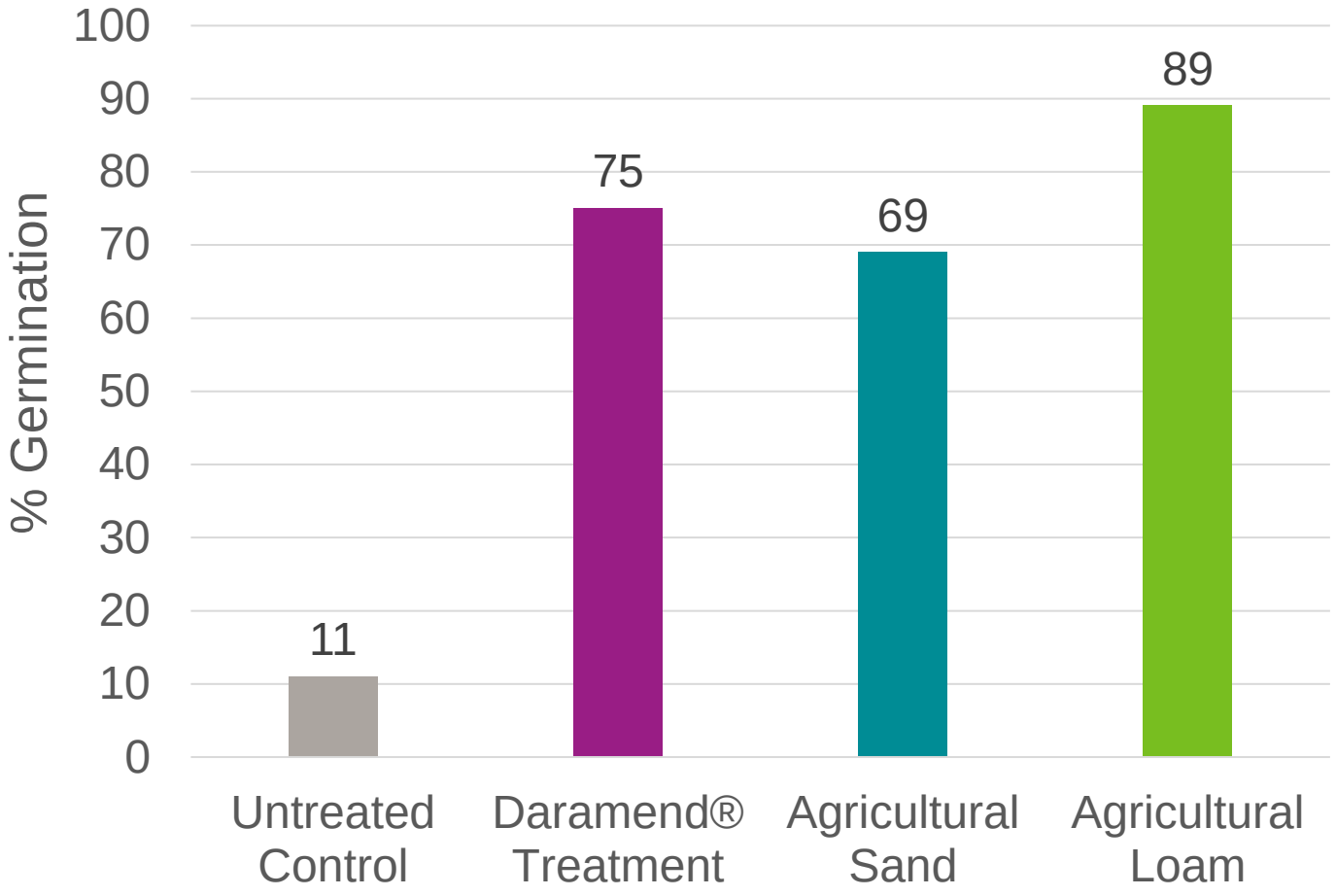
	TNT Concentration (mg/kg)							
Sampling Zone	Batch One		Batch Two		Batch Three		Batch Four	
	Initial	Final	Initial	Final	Initial	Final	Initial	Final
1	14,000	4.1	240	4.0	1,520	0.6	12,400	2.0
2	7,900	6.5	3,500	5.6	2,400	10.4	5,700	12.0
3	12,000	3.1	1,600	7.1	1,560	0.5	43,400	2.4
4	17,000	7.0	38,650	3.6	8,000	1.0	351	1.3
5	19	2.6	7,000	0.25	2,210	2.7	929	1.3
6	5,100	5.7	5,900	3.3	15,500	11.5	192	1.0
7	33,000	8.8	9,300	1.8	30,200	5.7	19.5	1.2
8	1,300	2.9	31,873	1.2.0	10,900	2.0	5,870	1.1
9	8,400	14.0	1,000	14.0	40,400	9.5	333	0.8
10	2,800	6.8	1.7	4.0	40,900	8.8	12,000	12.6
Mean	**10,151**	**6.2**	**9,906**	**4.5**	**15,359**	**5.3**	**8,119**	**3.6**

Project Notes

- ✓ Unexpectedly high initial TNT concentrations
- ✓ Still had excellent removal with attainment of remedial standard for each sampling zones in all seven batches
- ✓ Attainment of the 14 mg/kg standard for TNT required between 1 and 6 treatment cycles dependent on initial TNT concentration
- ✓ Daramend dosage was 0.5% w/w per cycle
- ✓ Some RDX was also present in the sediment, and it was also effectively treated to below the was remedial goal of 5 mg/kg

Project Snapshot 3: NWS Yorktown

Influence of Daramend® Treatment on Seed Germination in NWS Yorktown Soil



Toxicity Removal to Allow Revegetation

- An issue with other treatment approaches has been residual toxicity from accumulated aminonitrotoluene compounds
- Toxicity has been high enough to prevent establishment of good vegetation for erosion control
- To document removal of phytotoxicity tomato see germination studies were conducted
- Tomato seed germination is accepted as a direct measure of soil toxicity
- Tomato seed germination in Yorktown soil after Daramend remediation to the treatment standard was equivalent to agricultural soils collected from an agricultural research station with no history of pesticide use.

EVONIK Leading Beyond Chemistry

Sustainable Soil Amendments Summary
Terramend® & Daramend®

- ✓ Specialized organic soil amendments designed to enhance aerobic bioremediation for a many soil contaminants (Terramend®)
- ✓ Proven performance on full range of TPH, PAHs, PCP, phthalates, 2,4-D, and Lindane.
- ✓ Specialized organic + ZVI soil amendments designed to improve reductive degradation of chlorinated pesticides and nitroaromatic explosive compounds (Daramend®)
- ✓ Proven performance on most major chlorinated pesticides and organic explosive compounds including Lindane, DDT, Dieldrin, Chlordane.
- ✓ Also proven effective on organic explosive compounds (TNT, DNT, RDX, HMX, Tetryl)
- ✓ Very economical alternative to off site disposal for many soils, sediments, and industrial wastes
- ✓ Excellent 25-year worldwide track record in hundreds of field-scale applications

Questions
&
Answers

Enhanced Bioremediation of Soil Using Sustainable Soil Amendments

Evonik Soil & Groundwater Remediation
remediation@evonik.com
www.evonik.com/remediation

Dr. Alan G. Seech
Senior Manager,
Technology Applications
Evonik Active Oxygens

E. Alan.Seech@evonik.com
T. +1 949-514-1068
3334 E. Coast Hwy. #114
Corona Del Mar, CA 92625

EVONIK
Leading Beyond Chemistry


EVONIK
Leading Beyond Chemistry