



Termisk oprensning af PFAS forurenet jord – erfaringer fra projekter i USA sat i relation til Danmark

Gorm Heron, TRS Group og Søren Dyreborg, NIRAS

ATV møde d. 6. November 2024 : PFAS i jord og grundvand - hvad har vi lært?



Thermal Remediation of PFAS in Soil

Gorm Heron

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PFAS Boiling Points

Benzo(a)pyrene

500 °C

Dioxin

400 °C

PCB

300 °C

Naphthalene

200 °C

Xylene

PCE

100 °C

TCE

Carbon chain length

PFTeDS

PFOS
PFHxS
PFBS

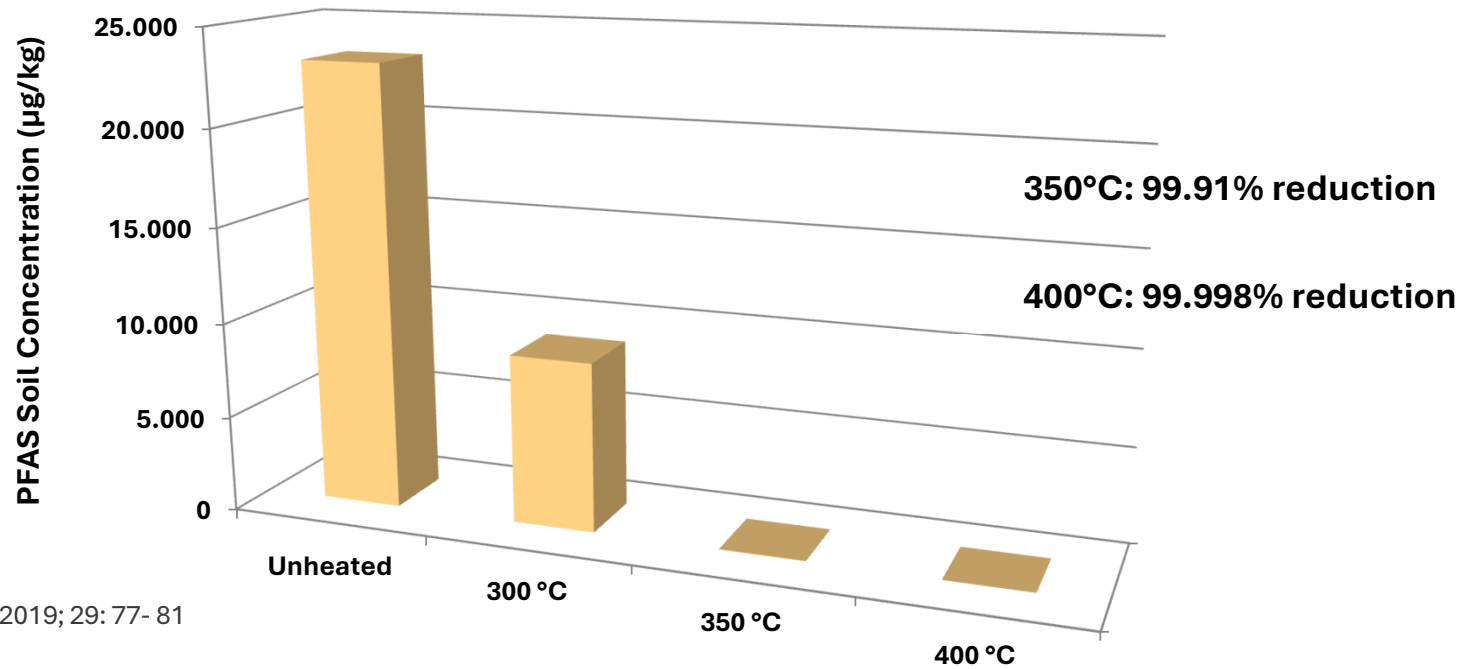
Sulfonates/
Sulfonic acids

PFDODA
PFDA
PFOA

PFHxA
PFBA

Carboxylates/
Carboxylic acids

Laboratory PFAS Treatment



Remediation 2019; 29: 77- 81

Two Weeks at Temperature

Eielson AFB: Heater Casing Installation



Thermal Barrier Construction



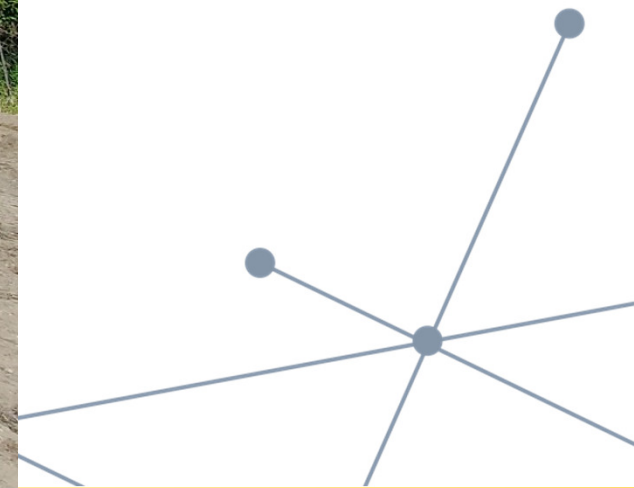
Thermal Barrier Construction





Stockpile Construction Complete

Water-resistant outer
layer and sealed edges

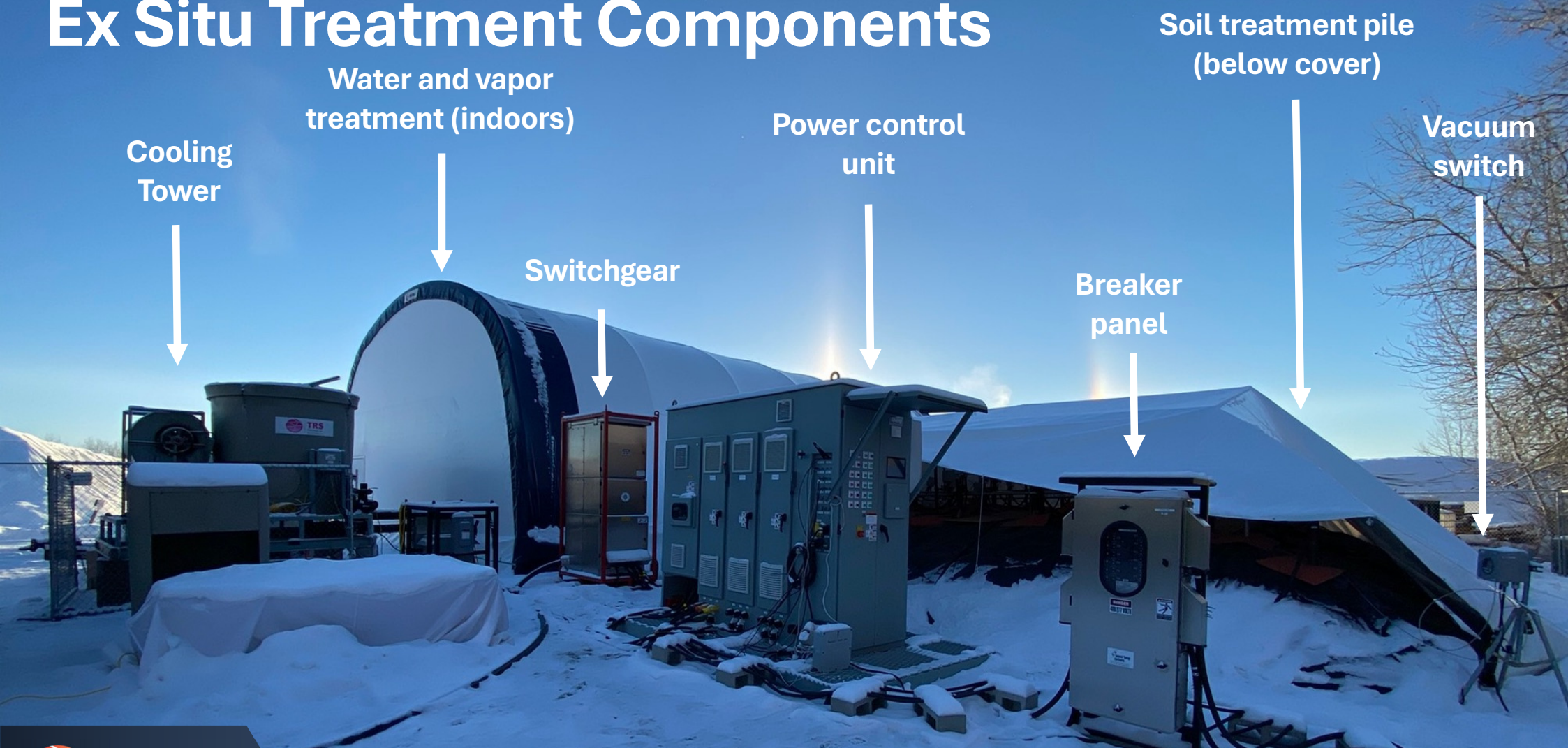


Winter Operations

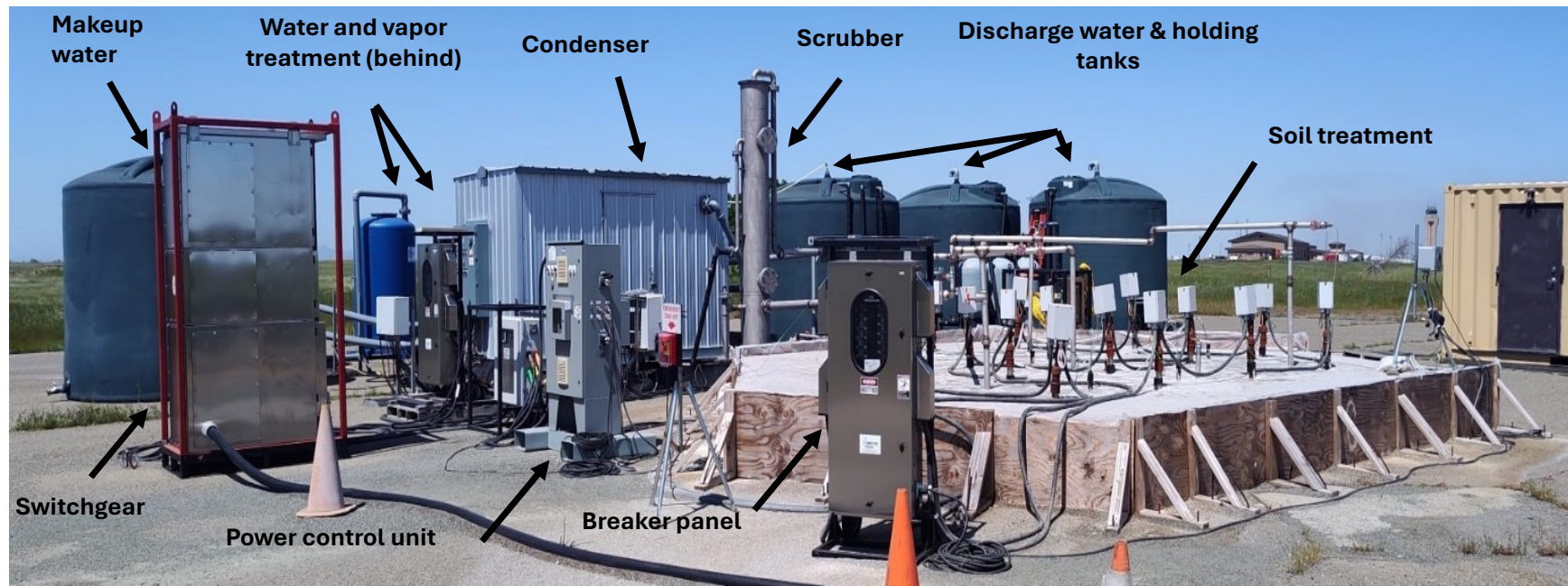
- Freeze protection
- Soil pile cover
- Equipment tent



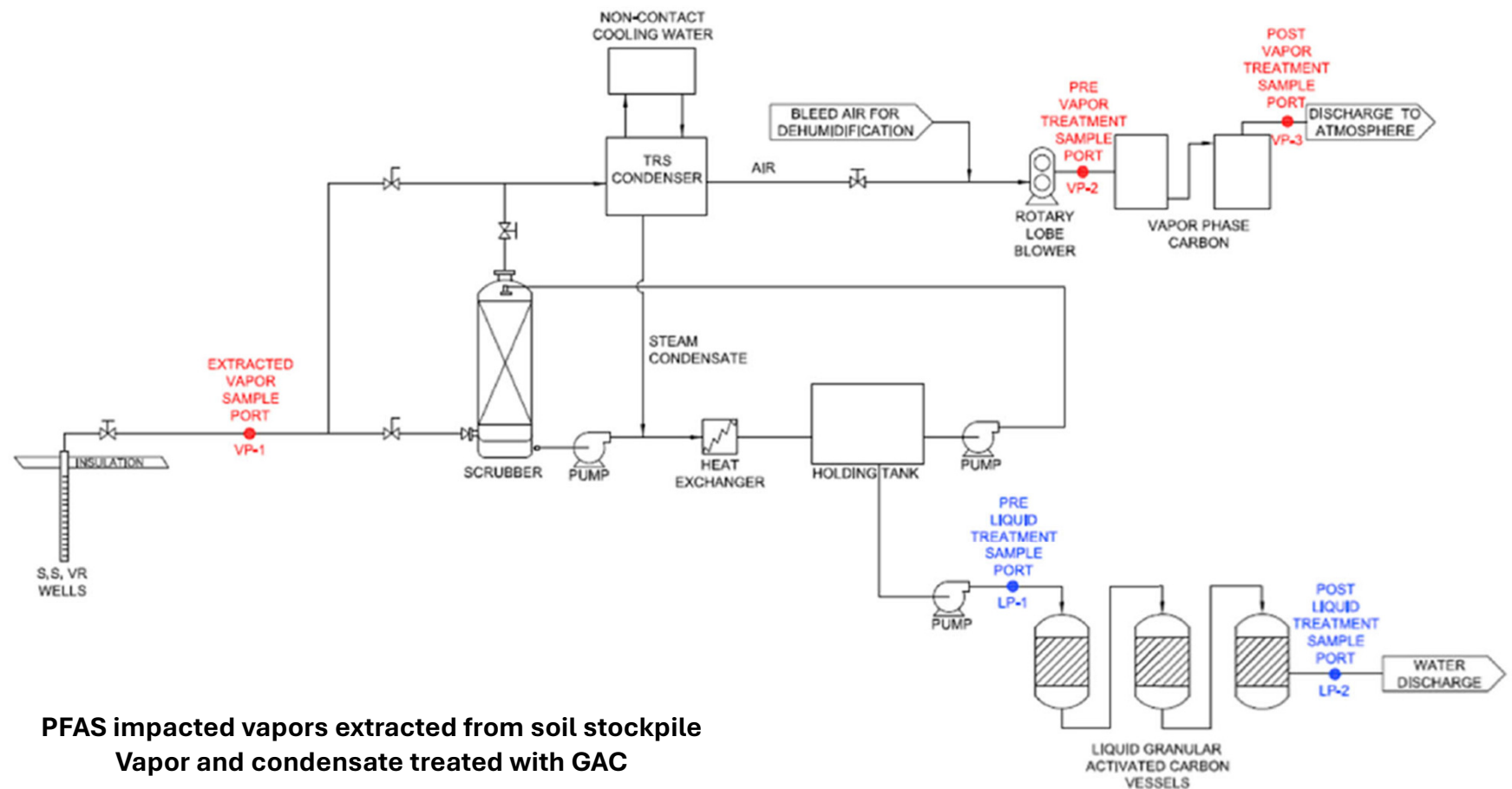
Ex Situ Treatment Components



In Situ Treatment Components

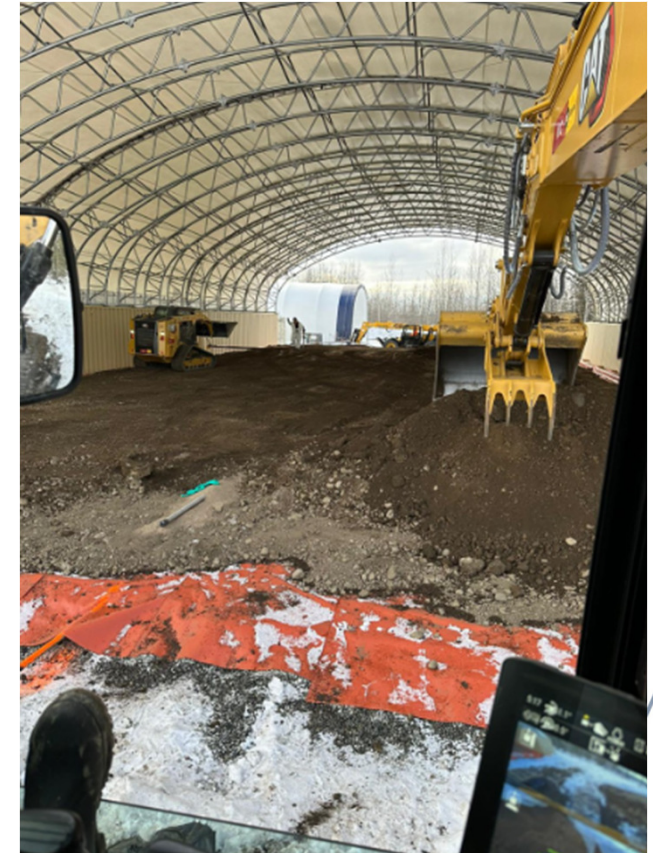


Process Stream Treatment



PFAS impacted vapors extracted from soil stockpile
Vapor and condensate treated with GAC

Joint Base Elmendorf-Richardson



Joint Base Elmendorf-Richardson



NAVFAC
Naval Facilities Engineering Systems Command
EXWC Engineering & Expeditionary Warfare Center

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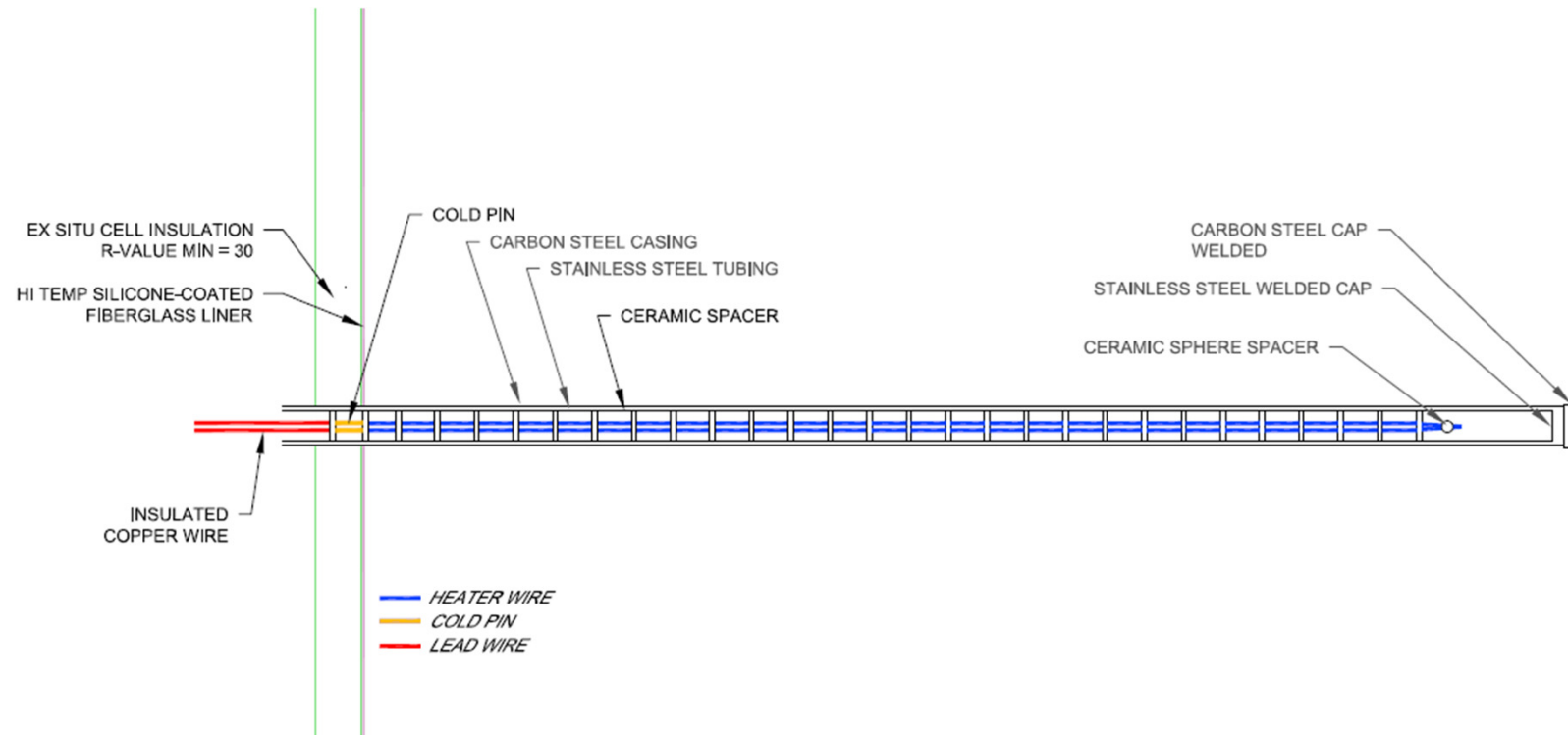
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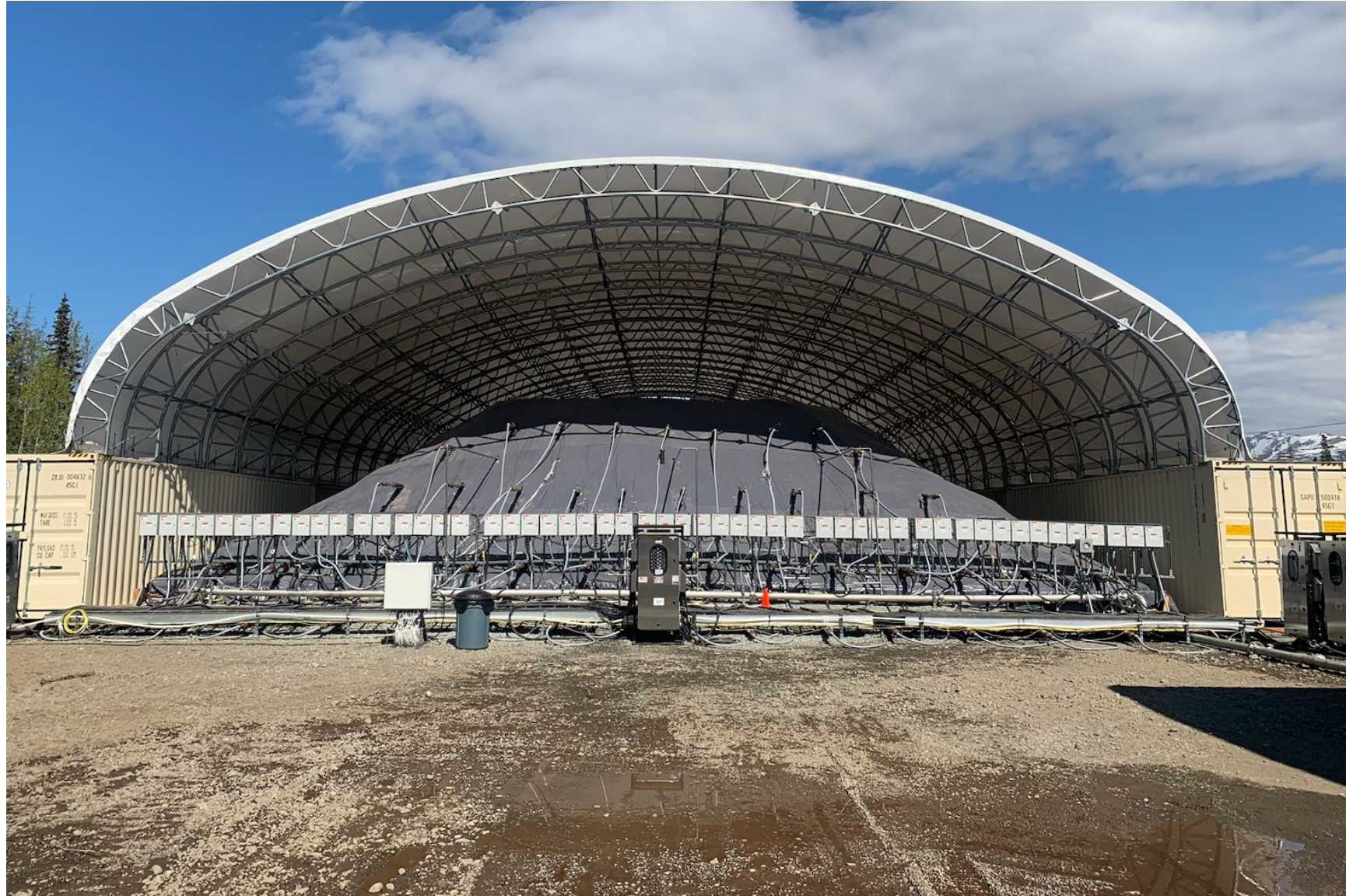
Joint Base Elmendorf-Richardson



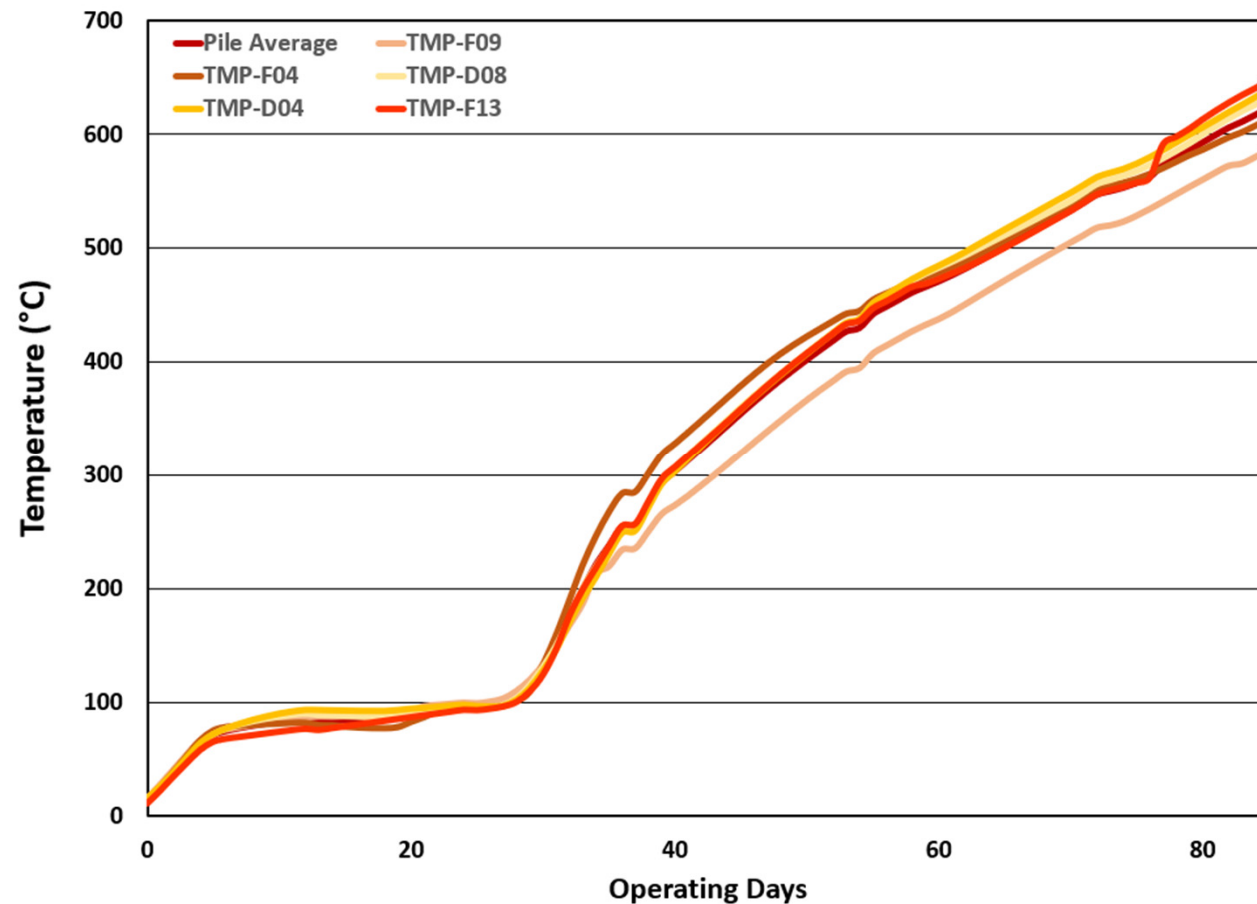
Heater Cross Section



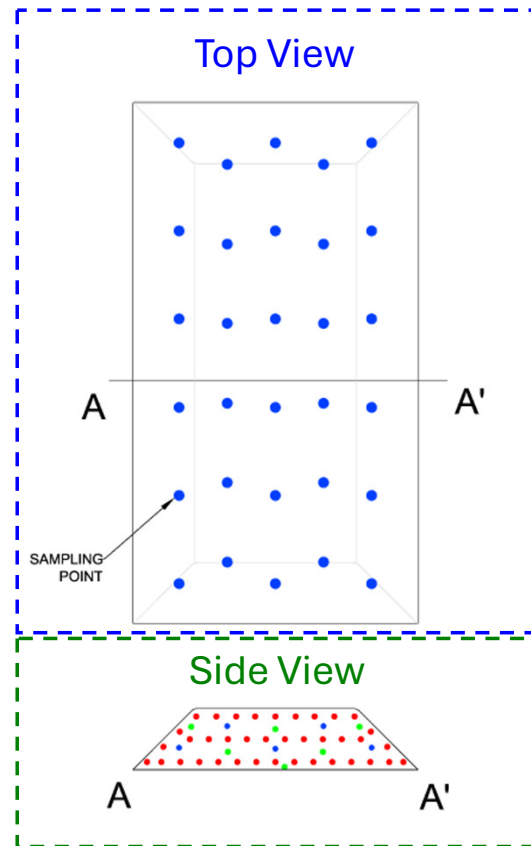
Joint Base Elmendorf- Richardson



JBER Soil Pile Temperatures



JBER Conceptual Layout



- Co-located soil sample and temperature sensor
- Horizontal heater
- Vapor extraction point

JBER Soil Results

Analyte	JBER Soil - Post TCH Max Concentrations (µg/kg)	Sample Location(s) Above ND	EPA Residential Soil RSL (TR 1E-06, THQ 0.1) (µg/kg)	ADEC MTG Soil Cleanup Level (µg/kg)	Laboratory Detection Limit (µg/kg)
PFBA	ND	-	7800	-	0.15 - 0.18
PFPeA	ND	-	-	-	0.0088 - 0.011
PFHxA	0.027 J	F04-60.8	3200	-	0.014 - 0.17
PFHpA	ND	-	-	-	0.02 - 0.026
PFOA	ND	-	0.019	1.7	0.07 - 0.085
PFNA	ND	-	19	-	0.05 - 0.066
PFDA	ND	-	-	-	0.039 - 0.051
PFBS	ND	-	1900	-	0.006 - 0.0079
PFPeS	ND	-	-	-	0.017 - 0.023
PFHxS	ND	-	130	-	0.018 - 0.024
PFOS	0.22	F09-5	0.63	3	0.023 - 0.028
6:2 FTS	ND	-	-	-	0.051 - 0.067
8:2 FTS	ND	-	-	-	0.049 - 0.065
PFOSA	ND	-	-	-	0.026 - 0.034
ADONA	ND	-	-	-	0.0079 - 0.011
PFMPA	ND	-	-	-	0.0052 - 0.0069
5:3 FTCA	ND	-	-	-	0.09 - 0.12
7:3 FTCA	ND	-	-	-	0.14 - 0.19

Results Summary

	Ex Situ Eielson AFB	In Situ Beale AFB	Ex Situ JBER
Peak Average Temp (°C)	415,8	406,3	637,9
Average post treatment PFOS (µg/kg)	3,1	1,75	<0,03
Energy used (kWh)	145.555	209.503	709.649
Heating duration (weeks)	12,9	20,5	11,7
Treatment volume (cy)	134/220	120/200	2.000
Energy density (kWh/cy)	1.086/660	1.746/1.000	346

1 cy = 0,76 m³

Regulatory Requirements

	Ex Situ Eielson AFB	In Situ Beale AFB	Ex Situ JBER
Target soil concentrations	Alaska DEC 3,0 µg/kg PFOS 1,7 µg/kg PFOA	ESTCP objectives 126 µg/kg PFOA, PFOS	Alaska DEC EPA Residential RSLs
Water discharge criteria compliance	PFOS, PFOA (0,4 µg/l)	Surface water ESVs PFOS (22,6 µg/l), PFOA (307 µg/l), PFBS (400 µg/l)	EPA MCLs PFOA, PFOS (4 ng/l) PFHxS, PFNA, HFPO-DA (10 ng/l)

Vapor treatment and discharge OTM-45 data

Table 1. Vapor concentrations and PFAS mass flux estimates based on OTM-45 data. Some V1 data was omitted because it was not considered reliable.

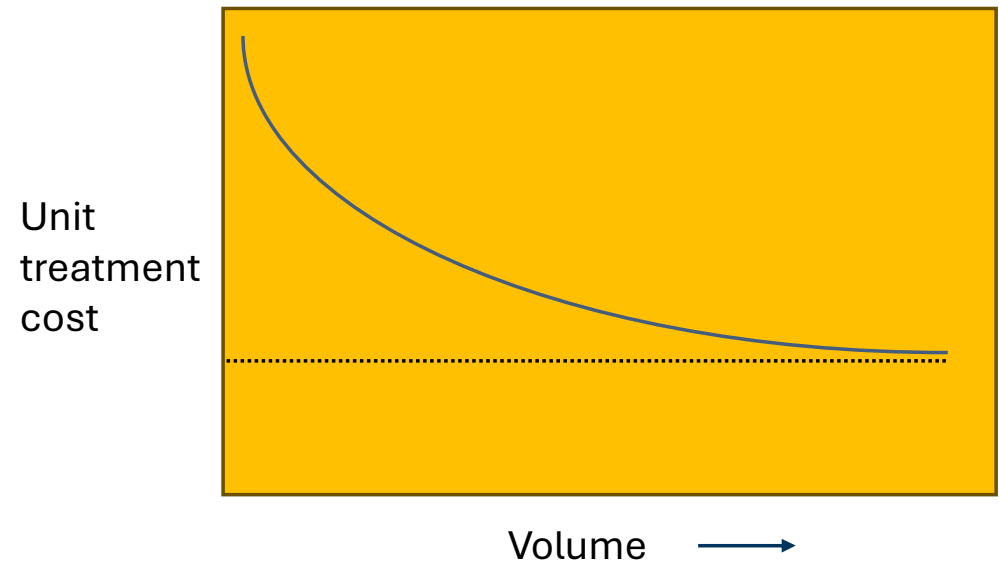
Day of operation	PFAS ng/L in pipe			scfm			ng/min			g/day			DRE (%)
	V1 PFAS	V2 PFAS	V3 PFAS	V1 flow	V2 flow	V3 flow	V1 flux	V2 flux	V3 flux	(from field)	(GAC inlet)	V3 flux (stack)	
0													
37	6.189	1.106	0.237	500	218	229	83,550	6,510	1,465	0.12031	0.00937	0.00211	98.25
64	#N/A	0.314	0.0453	#N/A	233	204	#N/A	1,975	250	#N/A	0.00284	0.00036	#N/A
71	#N/A	0.113	0.013	#N/A	243	226	#N/A	741	79	#N/A	0.00107	0.00011	#N/A
92	#N/A	0.2	0.102	#N/A	232	210	#N/A	1,253	578	#N/A	0.00180	0.00083	#N/A
106	0.298	0.131	0.0417	500	236	124	4,017	835	140	0.00578	0.00120	0.00020	96.52
127	0.195	0.0873	0.0347	500	105	110	2,633	247	103	0.00379	0.00036	0.00015	96.09

Sustainability Analysis (SiteWise™)

Remedial Alternatives	GHG Emissions	Total energy Used	Water Consumption	Total NO _x Emissions	Total SO _x Emissions	Total PM ₁₀ Emissions	Accident Risk Fatality
	metric ton	MMBTU	gallons	metric ton	metric ton	metric ton	
TCH	26,13	3.970	1.400	0,071	0,076	0,015	0,000095
Incineration	779,64	11.700		0,832	0,843	0,358	0,000869
Landfill	423,59	7.140		1,230	1,110	1,790	0,000418

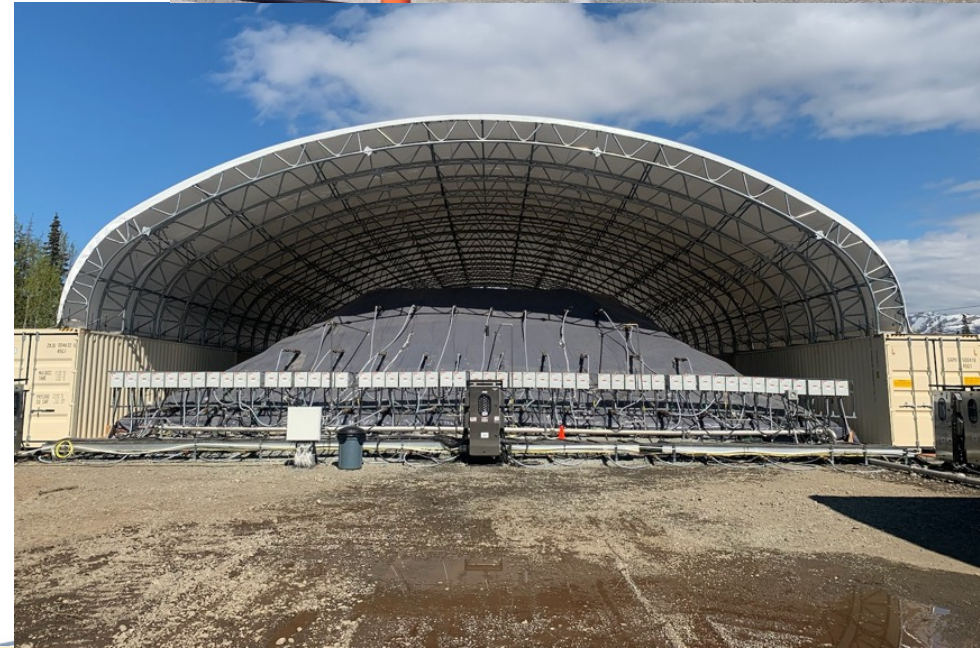
Treatment costs

- Electricity ~ 400 kWh per m³
- Scale dependent unit costs
- Above 500 Euro/m³



Key Points

- TCH in situ/ex situ – 400°C
- Treated to below Alaska DEC and EPA Residential RSLs
- 400 kWh/m³ plus heat losses
- Vapors treated on site, minimal waste
- Safe to discharge air and water



Acknowledgements



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Perspektiver for Danmark, termisk behandling v. Søren Dyreborg, NIRAS

- Ingen produktion af PFAS i Danmark => forventet lavere koncentrationer i jorden:
 - Regionernes database: brancher ”Overfladebehandling af metal” og ”brandvæsen og redningskorps”: maksimal koncentrationer < 5.000 µg/kg TS, men typisk meget lavere, fx i Korsør så vi ”kun” 1.449 µg/kg TS
 - Sammenlignet med 25.000 µg/kg fra USA
- Jordmængder ?
- Typer af jord : Typisk mere leret jordarter i DK => sværere at få luft ud af matrix
- Massebalancen, hvad ledes der ud (luft og vand) ?
- Økonomi, store jordmængder, USA : 500 EUR/m³ (ca. 2.000 kr/tons)



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Hvad er der ellers af perspektiver for Danmark, termisk behandling :

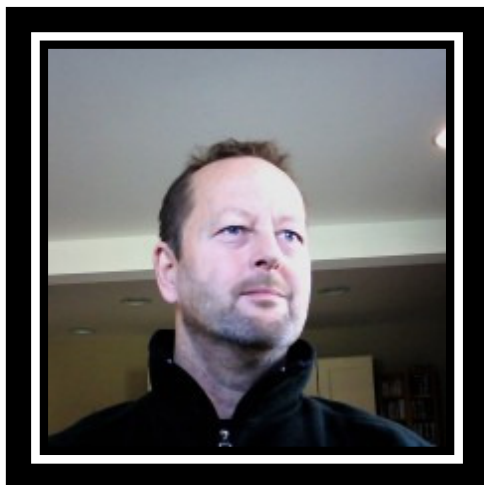
- On-side behandling, centralt ?
- Jordvask, med en reduktion af jordmængder (ler) ?
- Alternativer :
 - Eksport af jord til Norge ?
 - Stabilisering (immobilisering) af PFAS forurenet jord ved tilsætning af forskellige produkter (BioChar, RemBind, GAC, ..) ?



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