Evaluating In-Situ Thermal Remediation Technologies: Optimize your Selection Process

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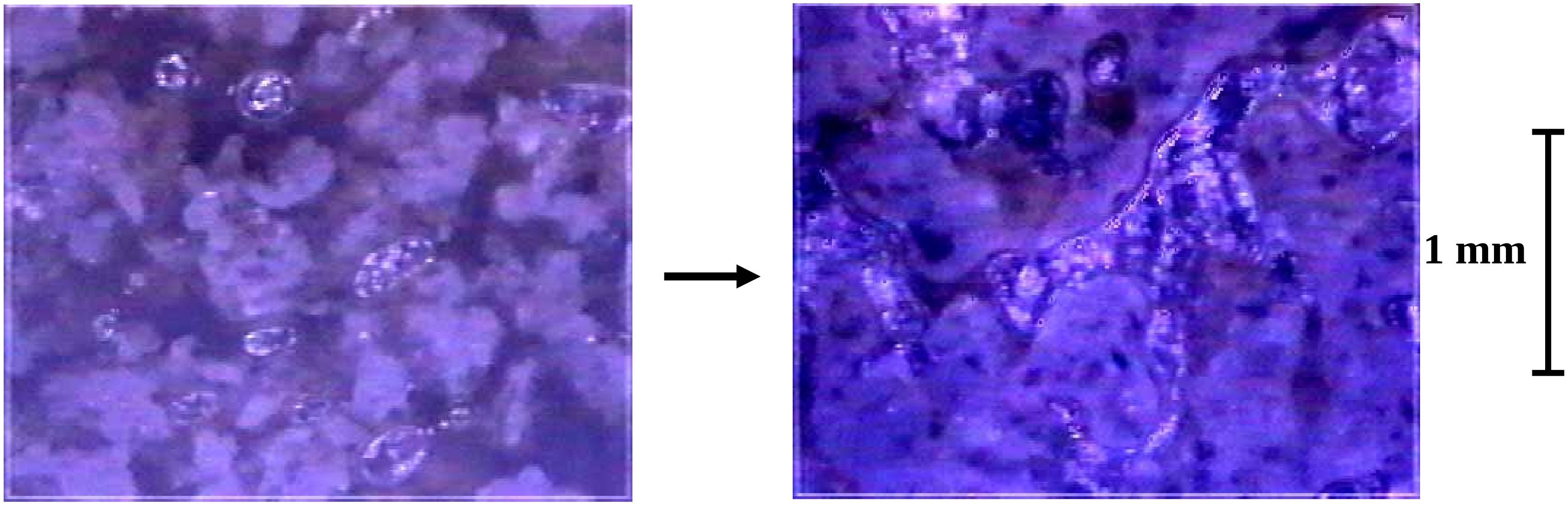
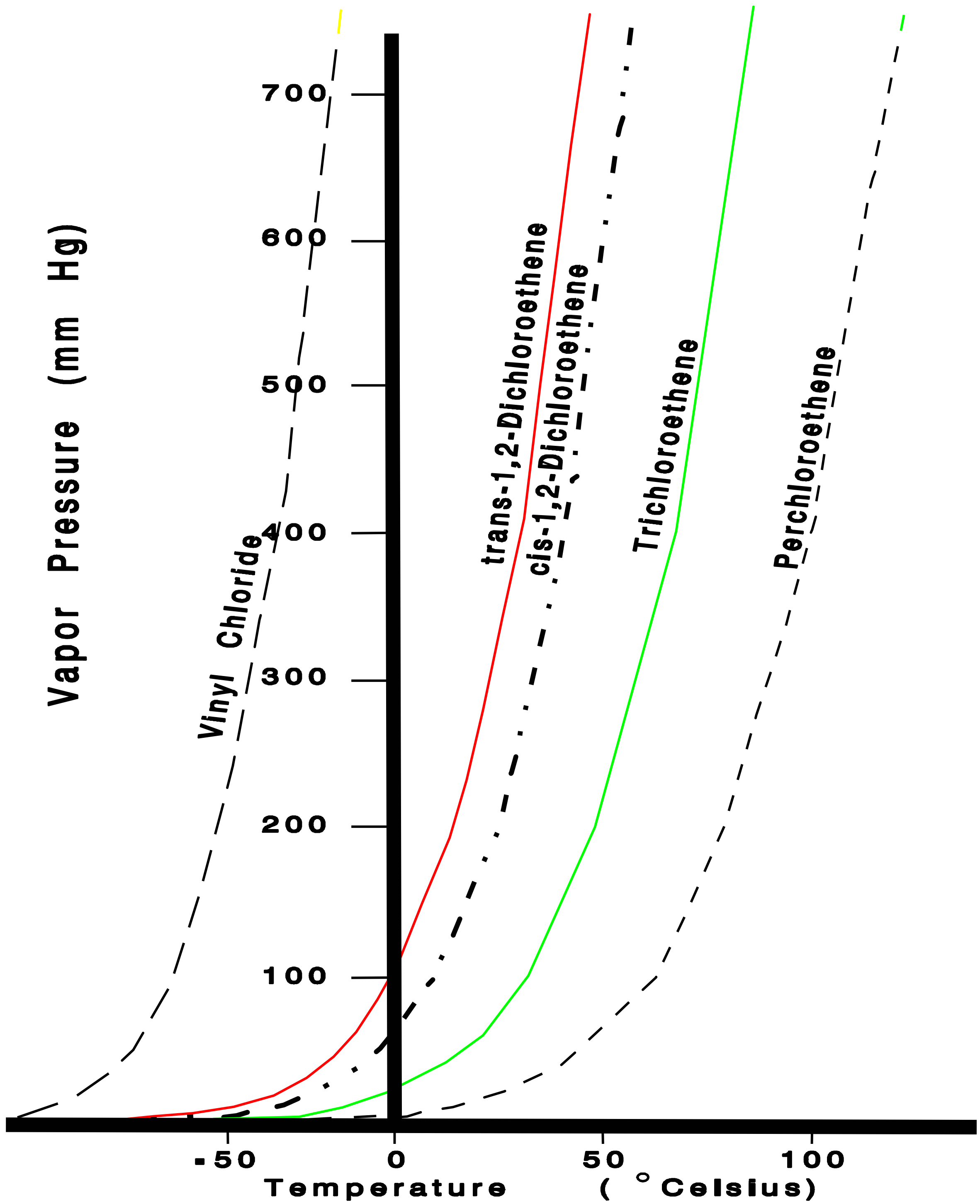
Thermal Treatment – Heat it Up



[Udell et al. 1999; Alameda Point SEE demonstration]

1. Remove NAPL

2. Polish to target concentrations



Vapor Pressure versus Temperature for Selected Chlorinated Alkenes

(Smith et al. 1994)

Physical Processes/Changes (below 120 °C)

Component property	Oil based LNAPL	Chlorinated solvents	Creosote	Coal tar	PCB	Comment
Vapor pressure increase factor	**20-80**	**20-100**	**20-300**	**20-300**	**2000**	Abundance of data in literature
Solubility increase factor	2-100?	1.5-3	10-1000	10-1000	10-1000	Chlorinated solvent less affected than larger hydrocarbons
Henry's constant increase factors		10-20	0-10	0-10	0-10	Data absent for most compounds, some decrease?
Viscosity reduction factor	2 to 100+	1.3-3	5-10	20-100+	3-100	The higher initial viscosity, the more reduction
Interfacial tension reduction factor	<2	<2	2-5	1-5	<5	Typically not dramatic effect (less than factor 2)
Density reduction (%)	10-20	10-20	10-20	10-20	10-20	Note that DNAPL may become LNAPL
K_d (reduction factor)	?	1-10	5-100	5-100	NA	Estimates based on limited data

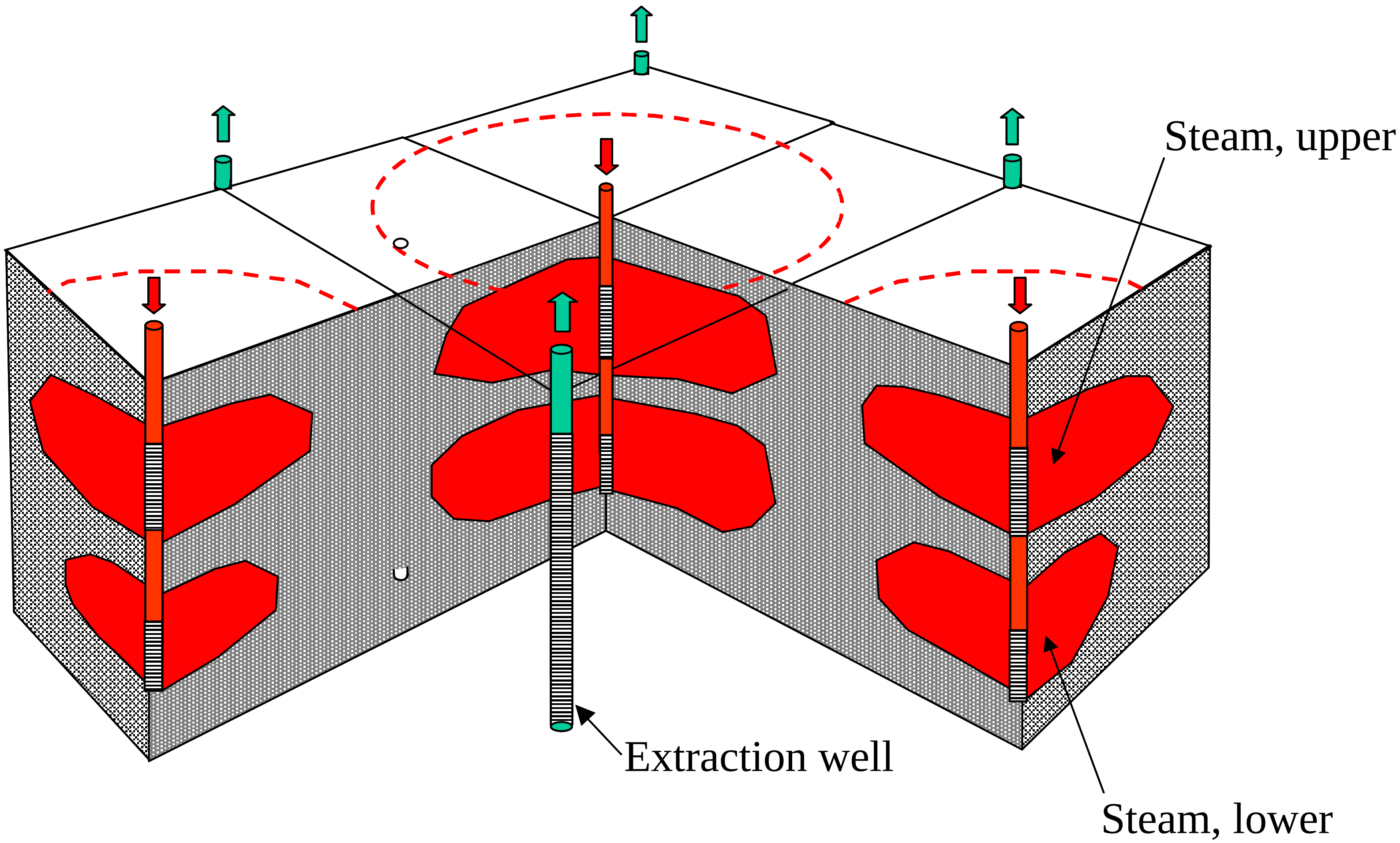
Udell (1989, 1991, 1993, 1996)
Davis (1997, 1999)
Imhoff et al. (1997)
Sleep and Ma (1997)
Heron et al. (1998, 2000)
Stegemeier and Vinegar (2001)

Note: Abiotic and biological reactions not listed

Consider In-Situ Thermal Remediation (ISTR):

- For Source Remediation of Organic Contaminants
- To Facilitate a Brownfields Cleanup
- To Achieve Rapid Site Closure
- As part of overall optimization of an existing system, especially where additional source control/removal would significantly shorten the duration of a long-term pump and treat, AS/SVE, Multi-Phase Extraction system.

Steam Enhanced Extraction (SEE)

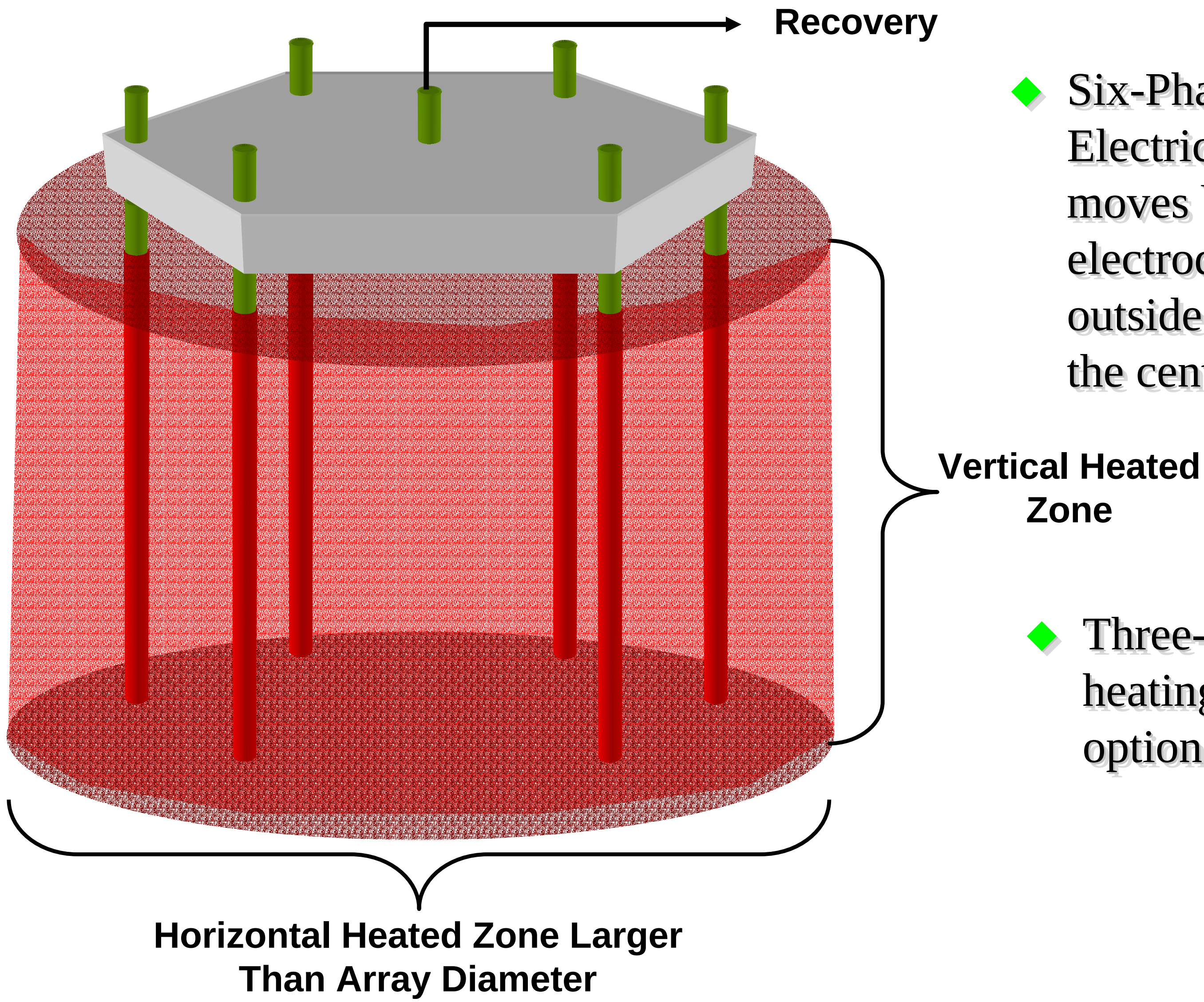


Summary of Recent SEE Results

Site Name	Contaminants	Depth (ft)	Volume (cy)	# wells	Starting contamination level	Post-treatment contaminant levels	Cost ($/cy)
Portsmouth Gaseous Diffusion Plant, OH	TCE	35	5,000	22	>500 mg/kg, ~ 1,000 lbs	~90% reduction in soils, removed 1,100 lbs	NA
Alameda Point, CA	TCE+diesel+motor oil	13	3,000	13	>3,000 mg/kg, >10,000 ug/L	99.8 % TCE mass reduction (<5 mg/kg, <50 ug/L)	300
Beale AFB, Marysville, CA	TCE	40	400	1	1,000 ug/L	80-90% reduction in target zone	NA
Edwards AFB, CA	TCE+GRO+DRO	60	2,000	5	NAPL in fractures, >2,000 lbs in source zone	ND above water table (<10 ug/kg TCE in rock chips), 50-90% dissolved TCE reduction below water table	150
Young-Rainey STAR Center Area A, FL	TCE,Toluene, MeCl2, DCE, TPH	34	14,000	51	LNAPL and DNAPL, >500 mg/kg VOCs, >100,000 ug/L TCE	<0.03 mg/kg VOCs, <30 ug/l TCE	265
Visalia Pole Yard	Creosote	140	400,000	30	NAPL and >1,000 mg/kg	<MCL in compliance wells	65

(Courtesy of G. Heron, 2004)

Electrical Resistance Heating (ERH)



Courtesy of CES

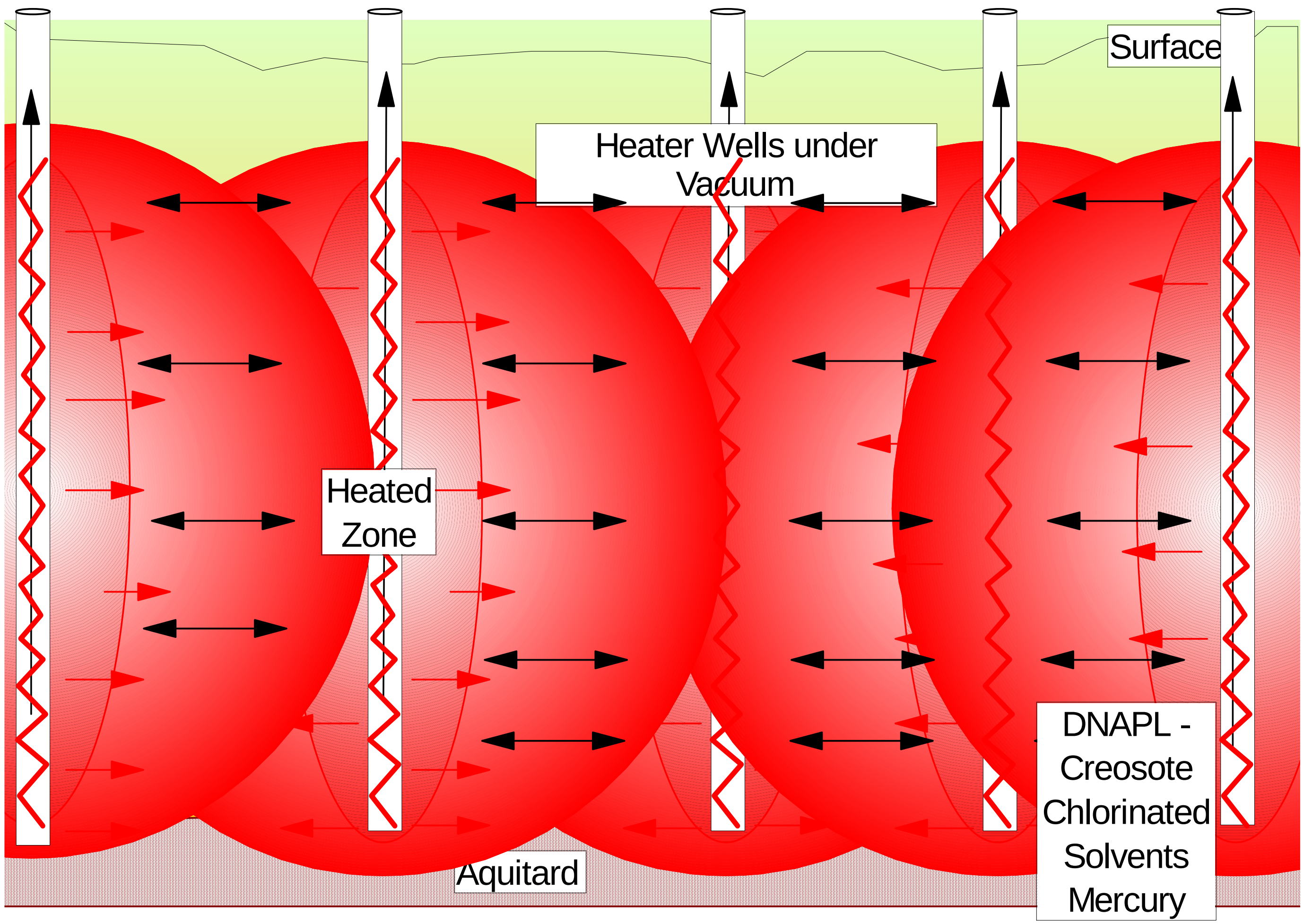
- Six-Phase Heating: Electrical current moves between the 6 electrodes on the outside diameter and the central neutral.
- Three-Phase heating is another option

Summary of Recent ERH Results

Site	Major COC	Depth (ft)	Volume (CY)	Electrode Spacing (ft)	Remedial Goals	% Removal	$/CY
AF Plant 4, Ft. Worth, TX	TCE	35	24,000	19	met	97	130-140
IR Site 5, Alameda Pt., CA	1,1,1-TCA	30	17,000	20	met	99	
Paducah, KY	TCE	99	5,800		met	99	1200 (pilot)
Silresim, Lowell, MA	TCE	40	1,250	16.5	not met	96	1280 (pilot)
Dry Cleaner Chicago, IL	PCE	20	890	8 to 12	met	96	780
ICN Pharmaceut. Portland, OR	TCE	60			met	99.9	99

(Papers presented at the Fifth Int. Conf. on Remed. of Chlorinated and Recalcitrant Compounds, Monterey, CA: Peacock et al. 2004; Cacciatore et al. 2004; Beyke et al. 2004; Hayes and Borochaner, 2004; Hoenig et al. 2004; Peterson et al. 2004)

Thermal Conduction Heating (TCH) Combined with Vacuum: In-Situ Thermal Desorption (ISTD)



Representative TCH Results

Site	Major COCs	Depth (ft)	Volume (CY)	Initial Max. Concentration (ppm)	Final Concentration (ppm)*	Cost ($/CY)
Confidential Site, Portland, IN	PCE	20	5,300	3,500	< 0.5	
Confidential Site, OH	TCE	15	11,500	4,130	< 0.07	140
Shell Fuel Terminal, Eugene, OR	Benzene Gasoline/ Diesel	12	18,000	3.3 < 7.9 ft free product	< 0.044 free product removed	200
Former Mare Is. Naval Shipyard, Vallejo, CA	PCB	14	175	2,200	< 0.033	6,300 (Pilot)
Naval Facility Centerville Beach, Ferndale, CA	PCB	15	1,540	800	< 0.17	420
Southern California Edison, Alhambra, CA	PAH (B[a]P Eq.) Dioxins (TEQ)	100	16,200	30.6 0.018	0.022 0.00048	425

(**Stegemeier and Vinegar 2001; LaChance et al. 2004; Bierschenk et al. 2004**)

***All remedial goals met**

ISTR Technology Selection: Site-Related Considerations

- ISTR is for Source Areas – Has the Source Area been Delineated?
  - Note: Less characterization is needed within the treatment zone than for non-thermal technologies
- Potential Contraindications:
  - Chemicals that are explosive at elevated temperatures
  - Soil shrinkage, subsidence, foundation stability issues (fairly rare)
  - Limited access for drilling
  - Excessive surface water and/or groundwater flux into remediation area that cannot be economically controlled

Source: ISTR Unified Facilities Criteria (UFC), 2004
(prepared under aegis of US Army Corps of Engineers and USEPA)

ISTR Technology Selection Considerations (continued)

Condition	**Preferred Technology***
Boiling Point >180C	TCH
CoC Solid @ STP	TCH
CoC in fractured crystalline or carbonate rock, or clean indurated sandstone	TCH or SEE
CoC < 8’ deep	TCH or SEE
Metal debris or high TDS GW	TCH or SEE

***Based on mass removal, not necessary excluding others**

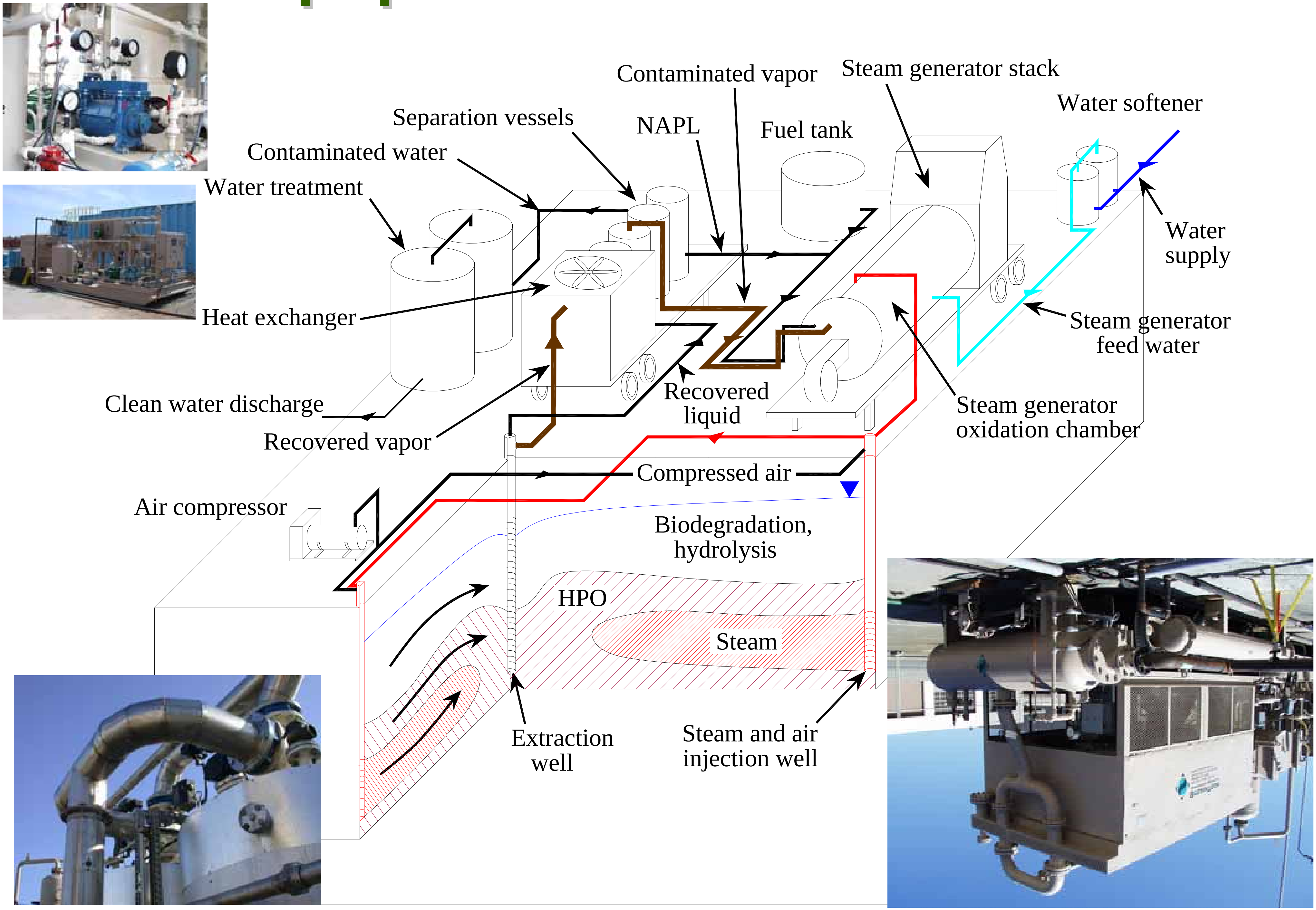
⇒ If none of these conditions apply, continue to screen via cost for each and relative to other options

(ISTR UFC, 2004)

Generalized Approach (whatever the ISTR technology)

1. Establish hydraulic and pneumatic control.
2. Heat the target volume (area, depth).
3. Optimize mass removal until COC recovery begins to drop off.
4. Optimize treatment and achieve diminishing returns.
5. Controlled cool-down and transition to polishing technique.

Equipment Considerations



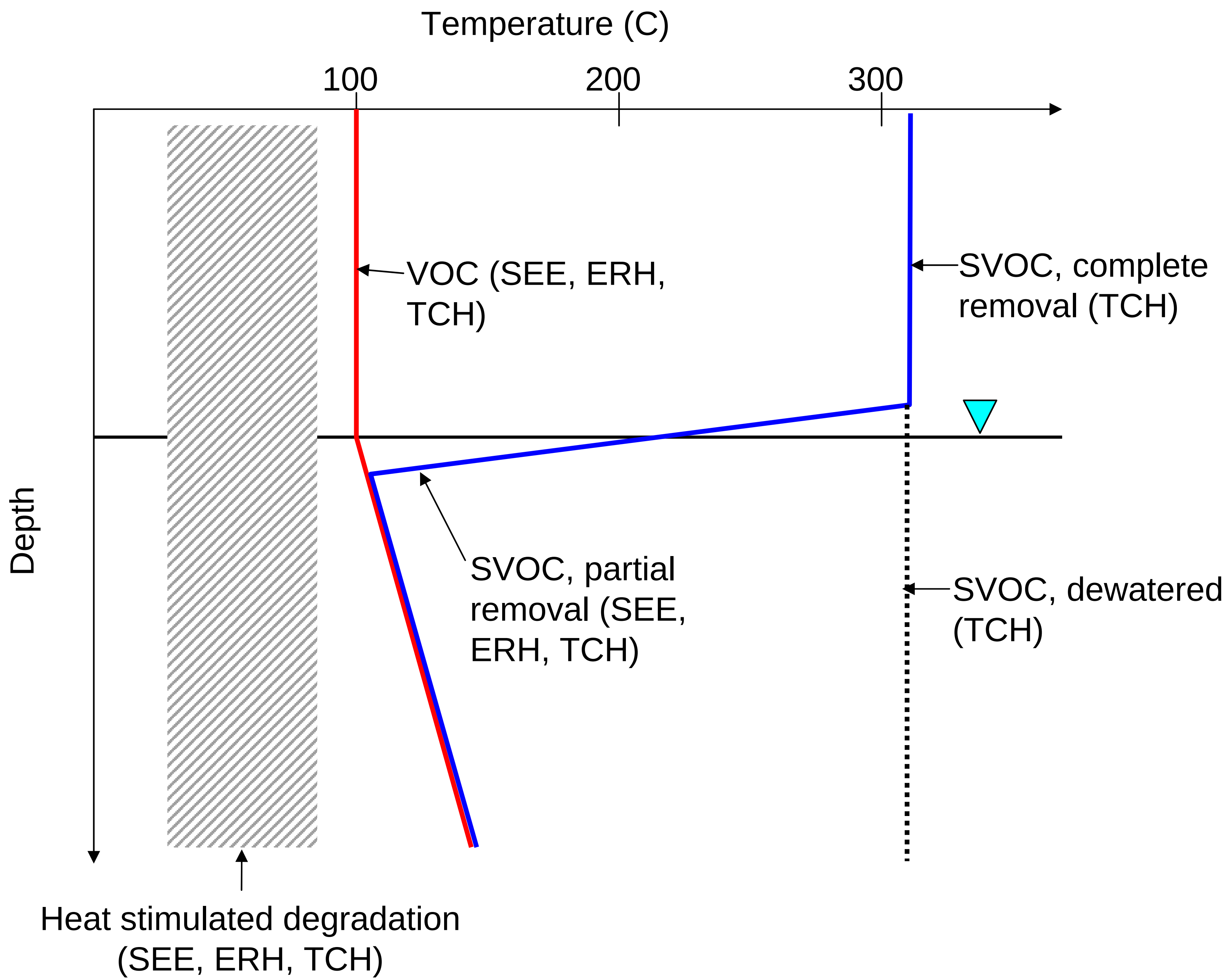
Equipment Considerations, cont.

- Utilize existing equipment where practical (plant steam, SVE, P&T)
- Materials compatibility important (temperature and chemical)
- Water treatment always for SEE, often necessary during ERH and TCH (groundwater and condensate)
- Off-gas treatment necessary – many different options and approaches (often driven by regulatory approval)

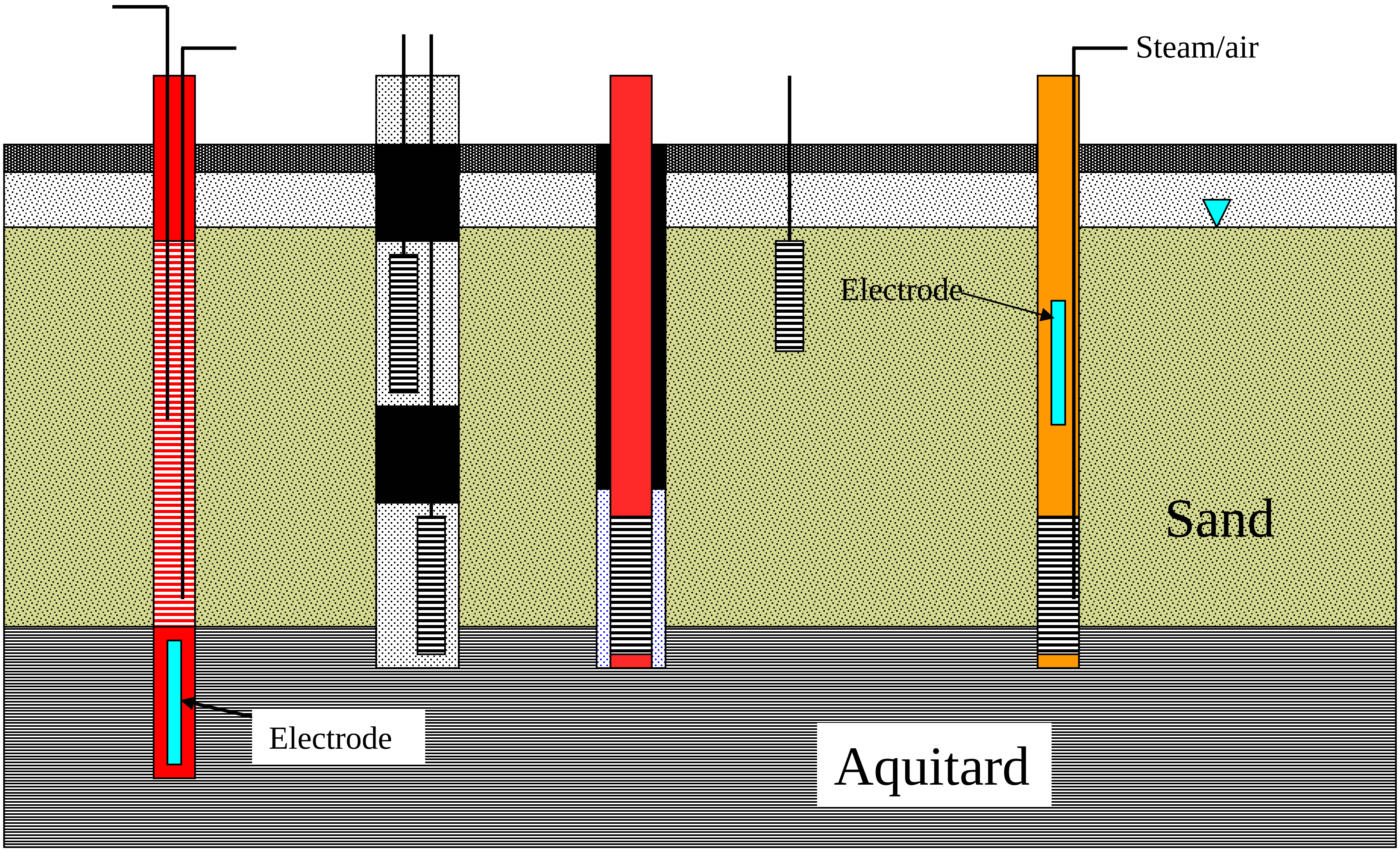
Cost Considerations

- Economies of Scale
- Depth – Deeper is Cheaper (on a unit cost basis)
- Water – Must address groundwater flux
- Off-gas Treatment – Function of regulatory requirements, CoCs, and estimated mass loading
- Contractual Terms – Performance guarantees add to the cost

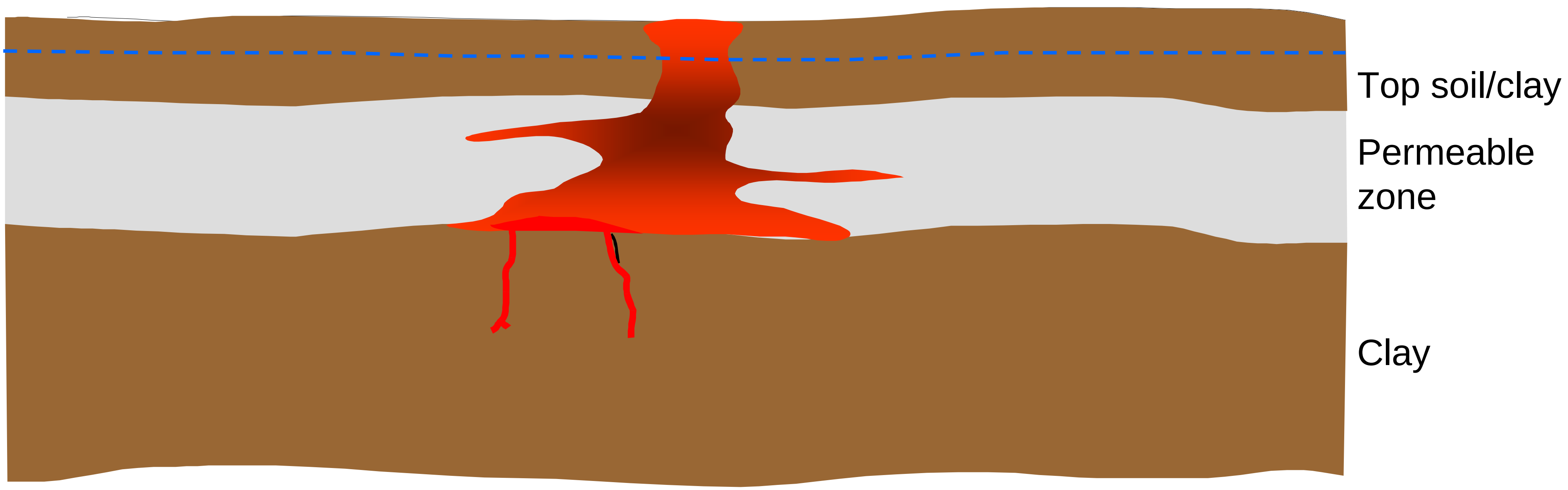
Target Temperatures

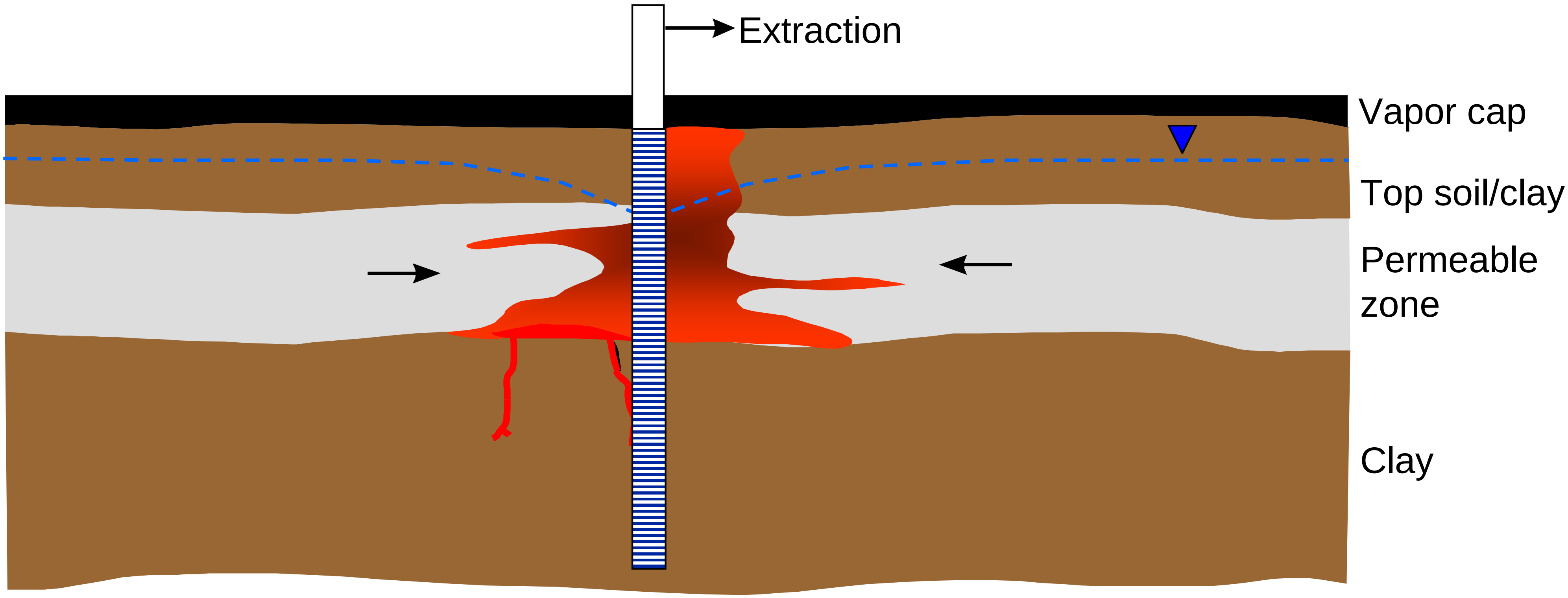


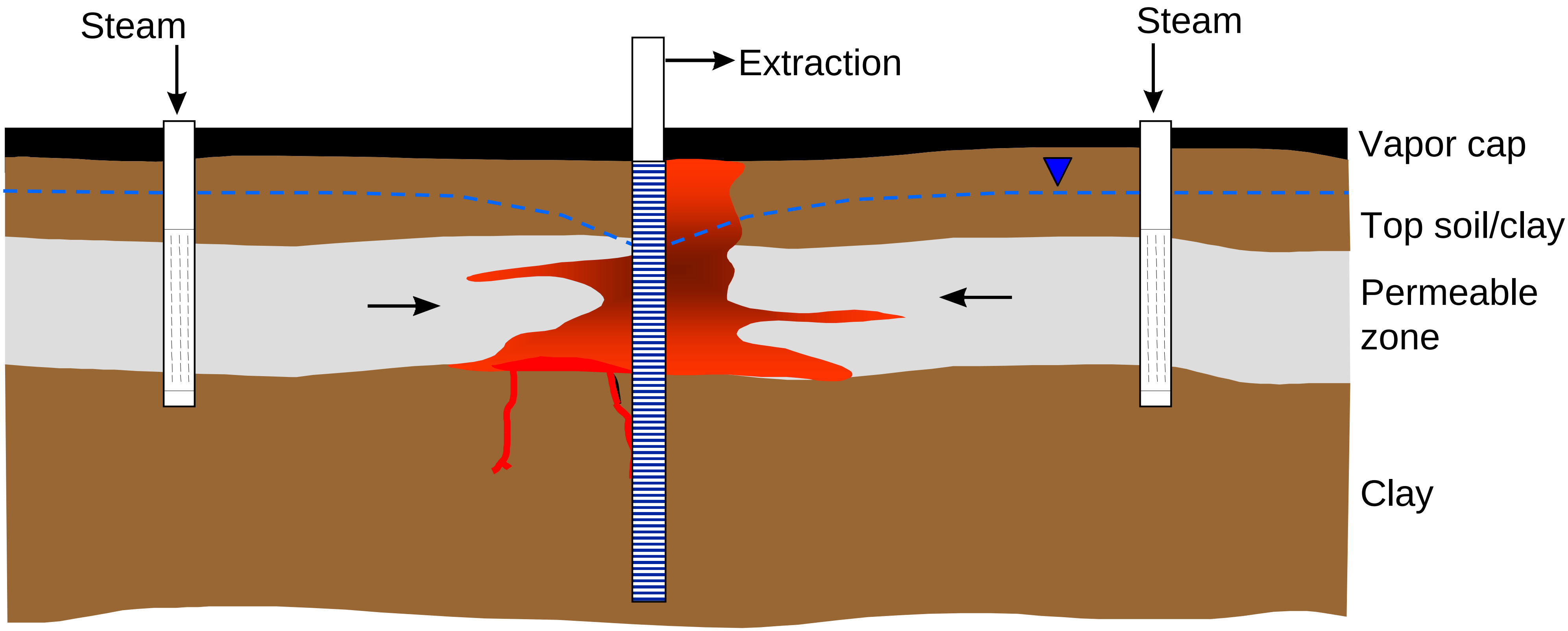
Dynamic Underground Stripping (DUS) for Complex Sites



DUS or TCH/SER in Complex Stratigraphy




Extraction
Vapor cap
Top soil/clay
Permeable zone
Clay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Extraction
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Vapor cap
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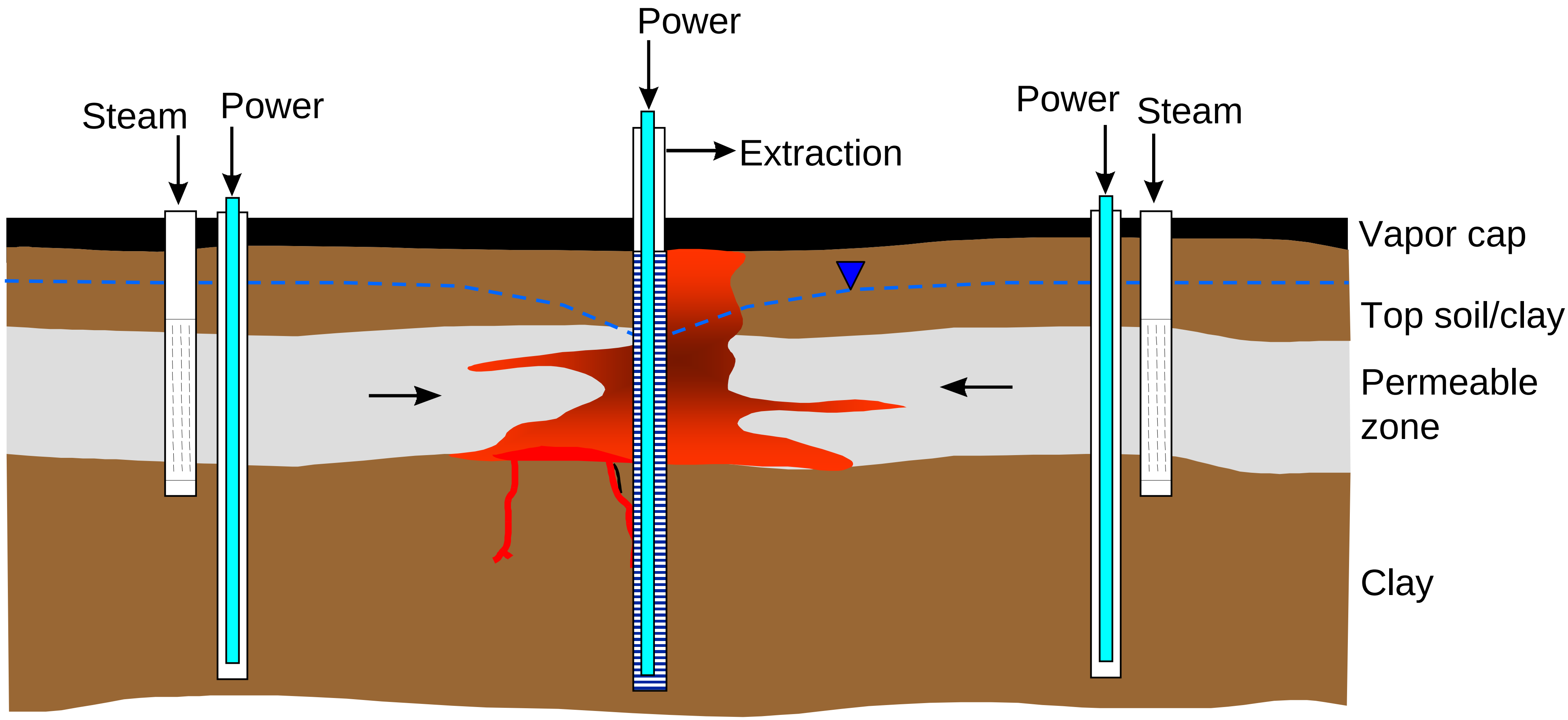
Permeable zone
Clay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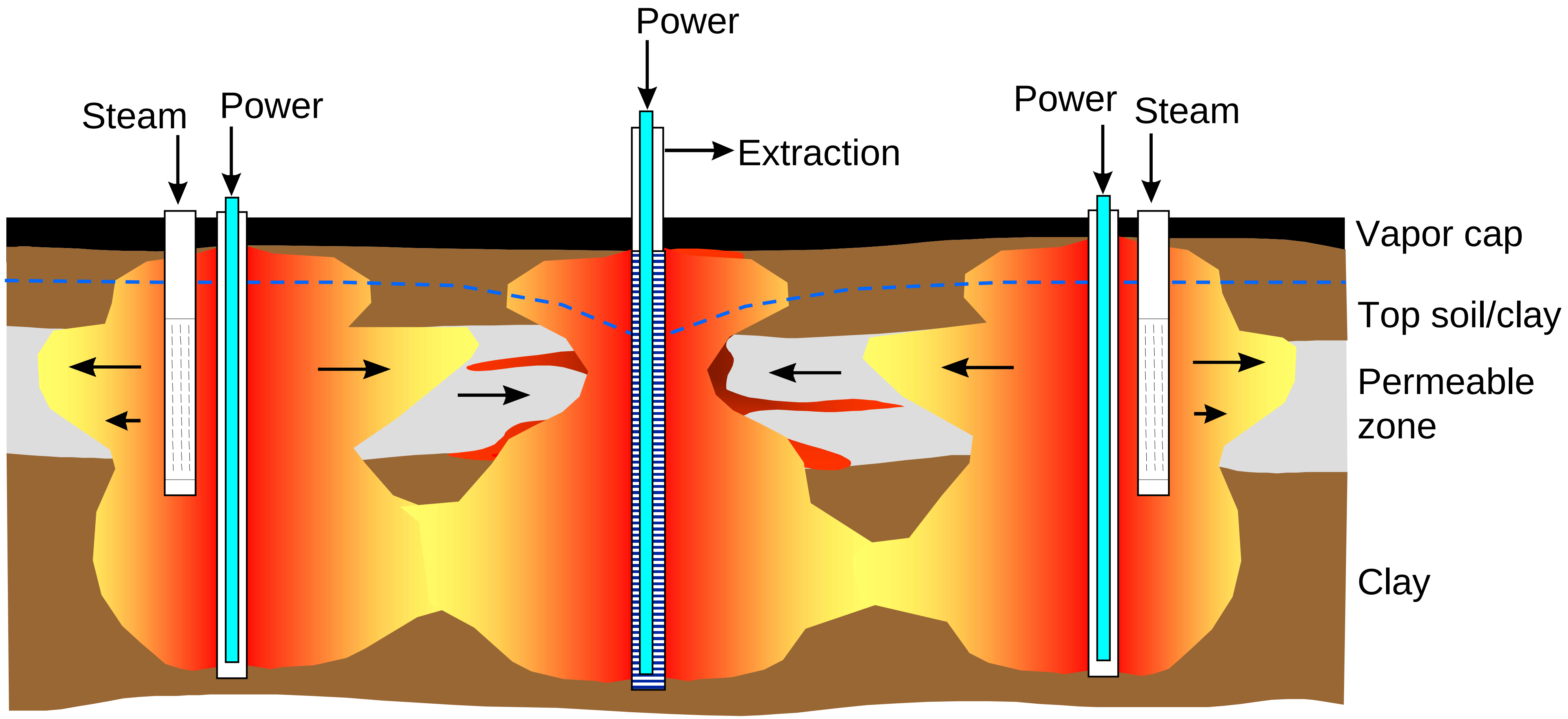
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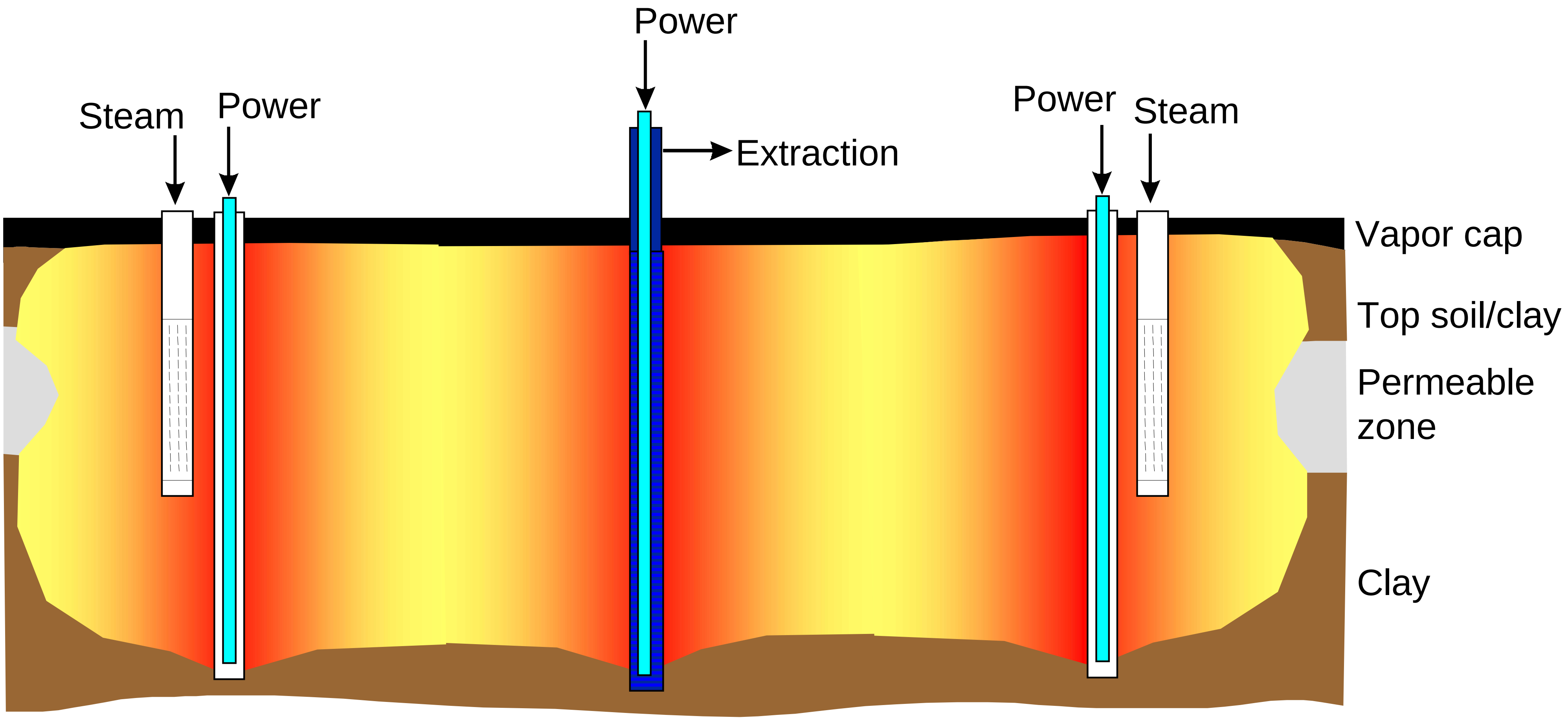

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Permeable zone
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Several Final Points

It’s not only about saving $ – If you’re optimizing on performance and effectiveness, cost shouldn’t be the only factor – let the chips fall where they may

Consider the life-cycle costs and benefits

- Environmental
- Energy Consumption