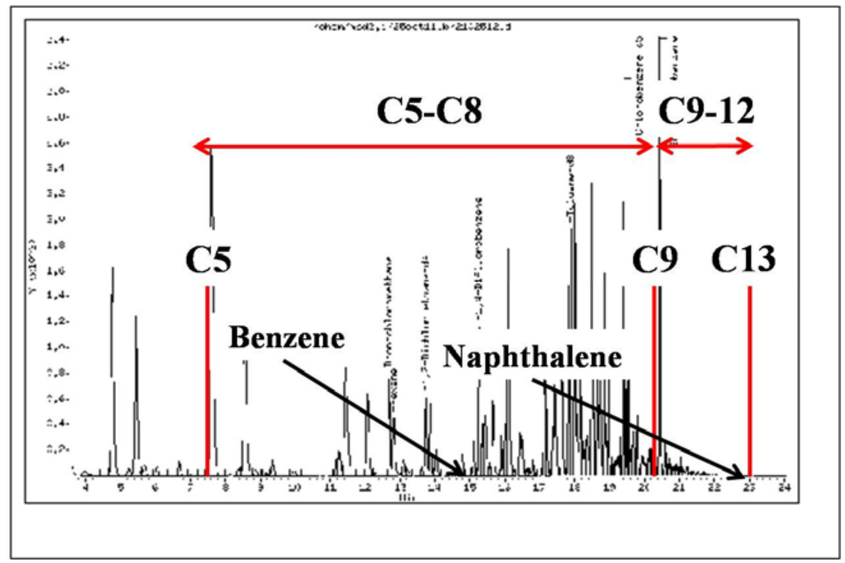
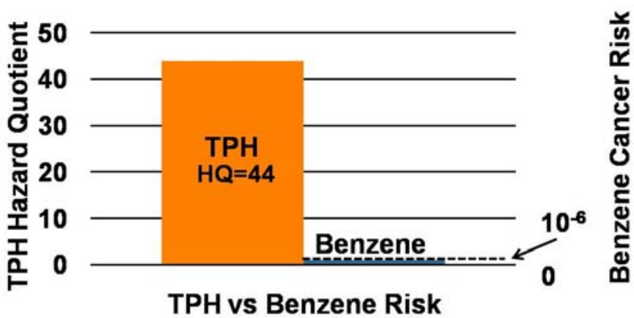
Petroleum Vapor Intrusion
Facts, Fallacies and Implications





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Acknowledgments

- **Lots of regulators, consultants and oil company scientists over the past twenty years;**
- **Field study discussed funded through HDOH grant from USEPA Region IX.**

<u>Third in Vapor Intrusion Webinar Series (recorded):</u>

1. **Climate-Based Vapor Intrusion Risk Regions and Region-Specific Screening Levels (HDOH, February 2015);**
2. **Collection and Interpretation of Active and Passive Soil Gas Samples (M. Schmidt & H. O'Neill, March 2015);**
3. **Petroleum Vapor Intrusion Review (HDOH, July 2015);**
4. **Long-Duration Indoor Air Samples and High-Purge Subslab Soil Gas Samples (coming this fall???)**

HEER Web Page: http://eha-web.doh.hawaii.gov/eha-cma/Leaders/HEER/Webinar

PVI Webinar Outline

- **Vapor Intrusion Basics;**
- **Evolution of Vapor Intrusion Science;**
- **Petroleum Vapor Intrusion FACTS;**
- **Petroleum Vapor Intrusion Semi-FACTS;**
- **Petroleum Vapor Intrusion Fallacies;**
- **Implications.**

Hawai'i DOH PVI References

Vapor Intrusion Action Levels: ***Evaluation of Environmental Hazards at Sites with Contaminated Soil and Groundwater***
http://hawaii.gov/health/environmental/hazard/

VI Field Investigations: ***Technical Guidance Manual*****: Hawai'i Department of Health,**
http://www.hawaiidoh.org/

Field Investigation of the Chemistry and Toxicity of TPH in Petroleum Vapors, Implications for Potential Vapor Intrusion Hazards (see also Brewer et al 2013)**: Hawai'i Department of Health**
http://www.hawaiidoh.org/

Recent Additional PVI References

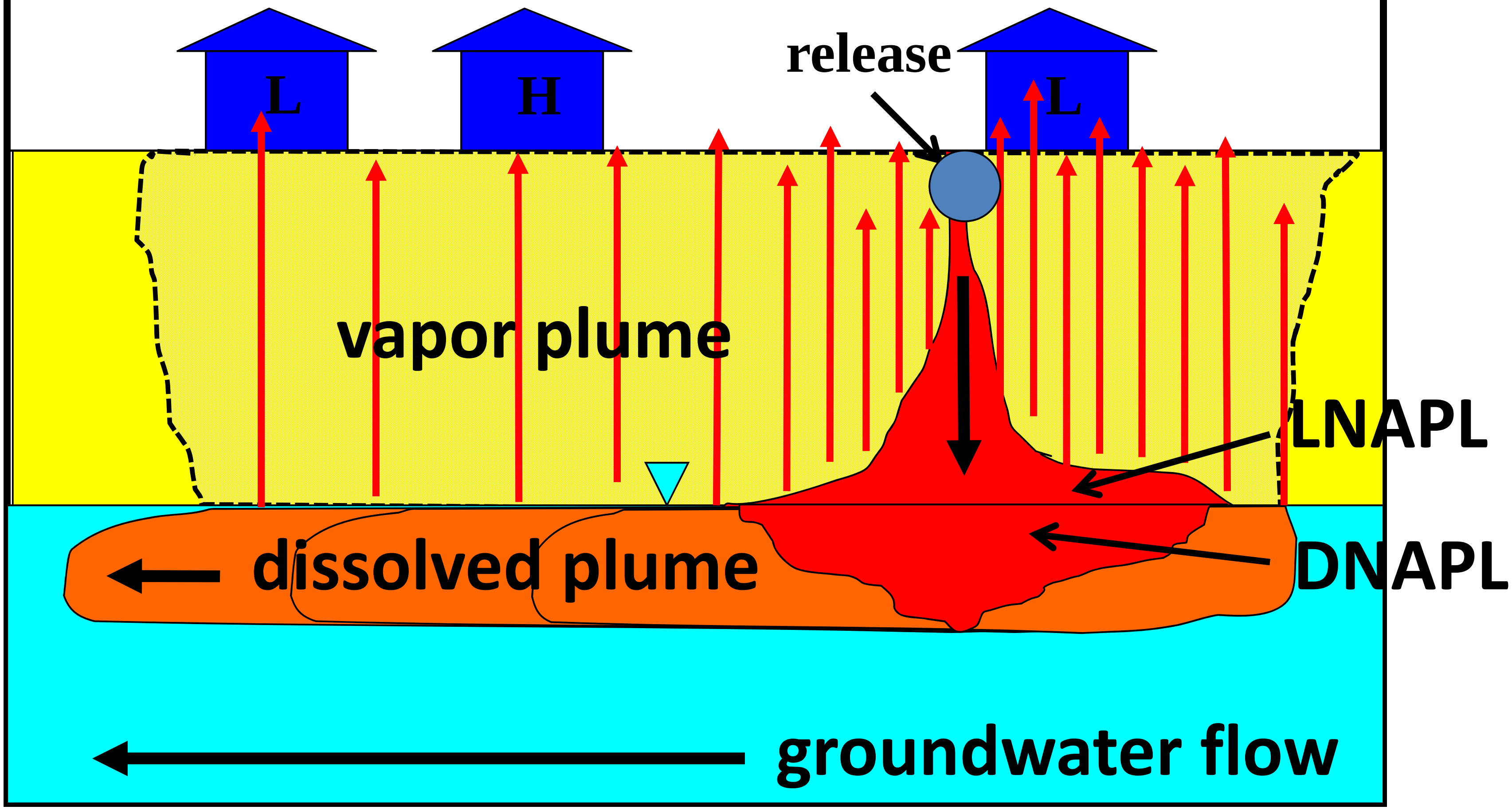
Technical Guide for Addressing Petroleum Vapor Intrusion at Leaking Underground Storage Tank Sites **(June 2015): US Environmental Protection Agency, EPA 510-R-15-001.**

Petroleum Vapor Intrusion: Fundamentals of Screening, Investigation, and Management **(October 2014): *Interstate Technology Regulatory Council (ITRC).**

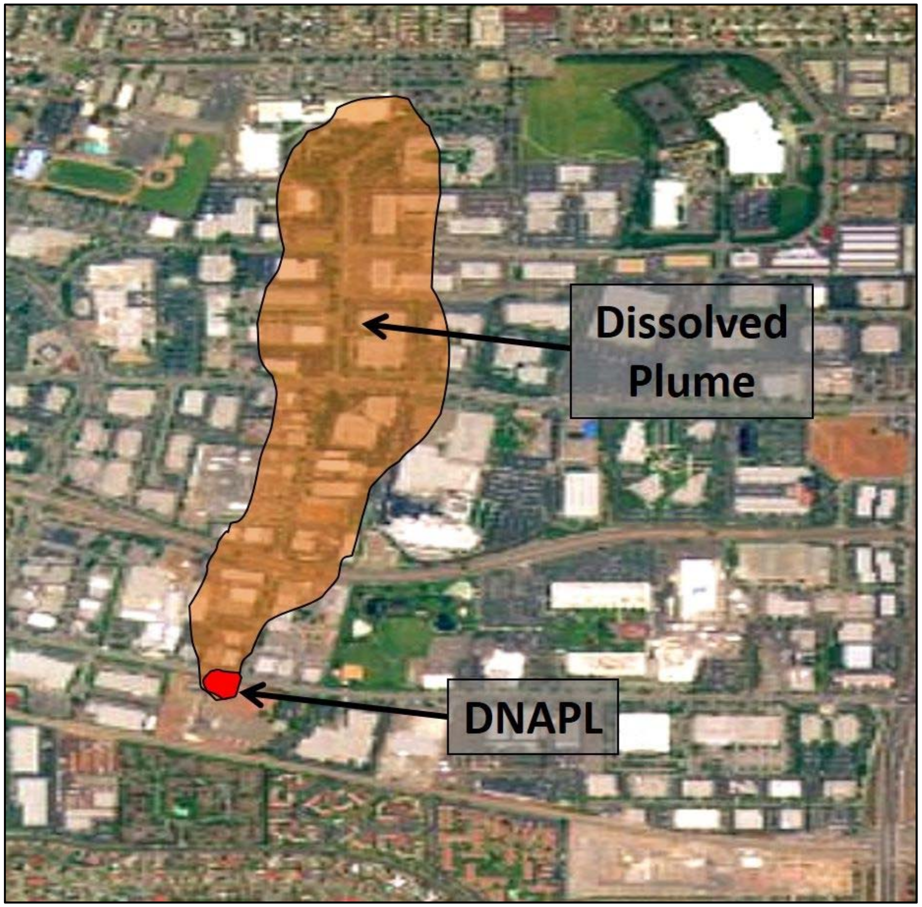
***Public-private coalition of regulators, consultants and industry representatives.**

Vapor Intrusion Basics

- Wind, exhaust fans, heating, etc., *under-pressurize* building (A/C can *over-pressurize* lower floors);
- Potential intrusion of subsurface vapors.



Evolution of VI and Chlorinated Solvents



<u>Pre-1990s</u>
- **VI not considered;**

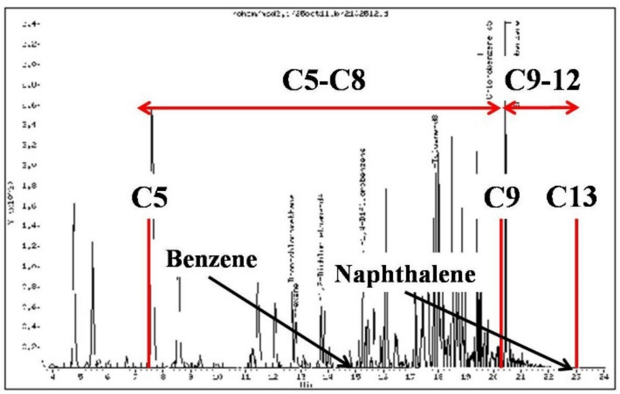
<u>Mid-1990s</u>
- **Possible VI risk from DNAPL;**

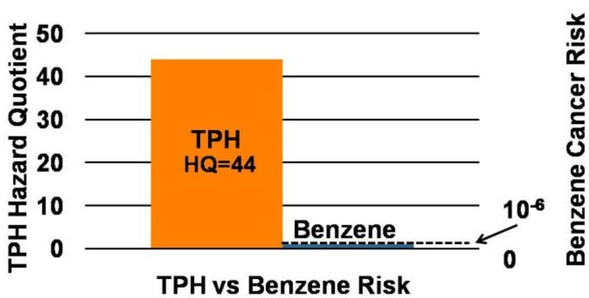
<u>Early 2000s</u>
- **VI risk from high-concentration dissolved plumes;**

<u>Mid 2000s</u>
- **VI risk from lower-concentration dissolved plumes;**

<u>Current</u>
- **Better understanding of building leakage and ventilation, attenuation factors, spatial and temporal heterogeneity, more representative samples, etc.;**
- **High-risk VI problems rare.**

Evolution of VI and Petroleum





<u>Pre-1990s</u>

- **VI not considered;**

<u>Mid-1990s</u>

- **Possible VI risk from shallow (<15ft) LNAPL (lower risk than solvents);**
- **Risk-based evaluation of TPH carbon ranges (mostly for soil);**

<u>Early 2000s</u>

- **Natural degradation limits on vapor transport widely recognized;**
- **Solvent models "don't work";**
- **Minimal risk from dissolved plumes;**

<u>Current</u>

- **Additional supporting data for reduced VI risk compared to solvents;**
- **Field studies of petroleum vapor plume chemistry;**
- **Updated guidance.**

PVI Webinar Outline

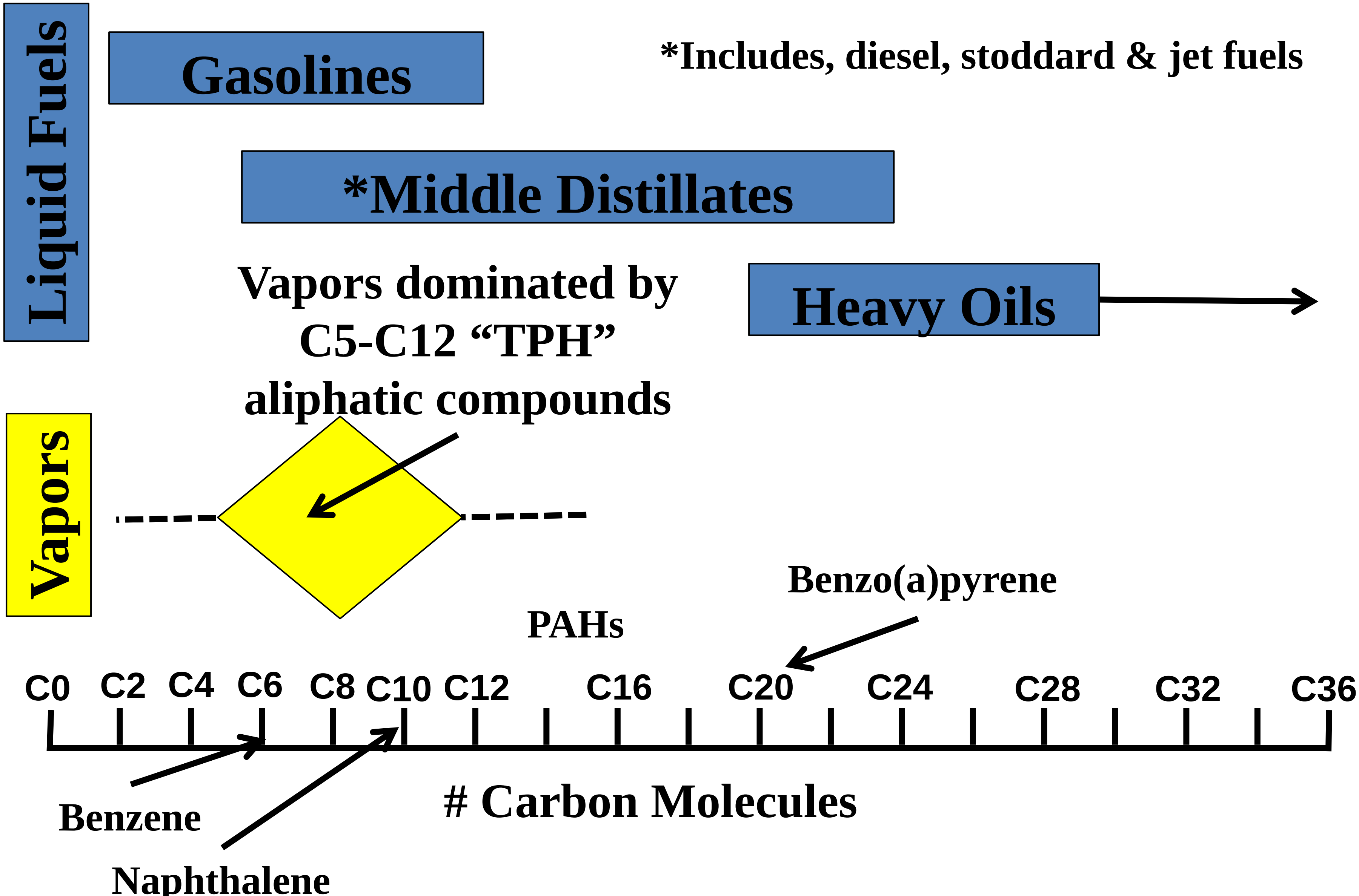
- **Vapor Intrusion Basics;**
- **Evolution of Vapor Intrusion Science;**
- **Petroleum Vapor Intrusion FACTS;**
- **Petroleum Vapor Intrusion Semi-FACTS;**
- **Petroleum Vapor Intrusion Fallacies;**
- **Implications.**

Petroleum Vapor Intrusion *FACTS

- **Both *chlorinated solvents and petroleum* can pose vapor intrusion risks under some circumstances;**
- **Total number of *petroleum-release sites* far outweighs number of solvent-release sites;**
- **Petroleum fuel vapors are dominated by *aliphatic* compounds (vs BTEXN);**
- **Natural *biodegradation* of petroleum vapors significantly reduces potential vapor intrusion risks;**
- **Models used for solvents significantly *over predict* vapor concentrations away from source area;**
- ***Field data* required to more accurately assess vapor intrusion risks (e.g., soil gas +/- indoor air).**

***Strong agreement between HDOH, USEPA & ITRC guidances**

Chemistry of Liquid Fuels vs Soil Vapors



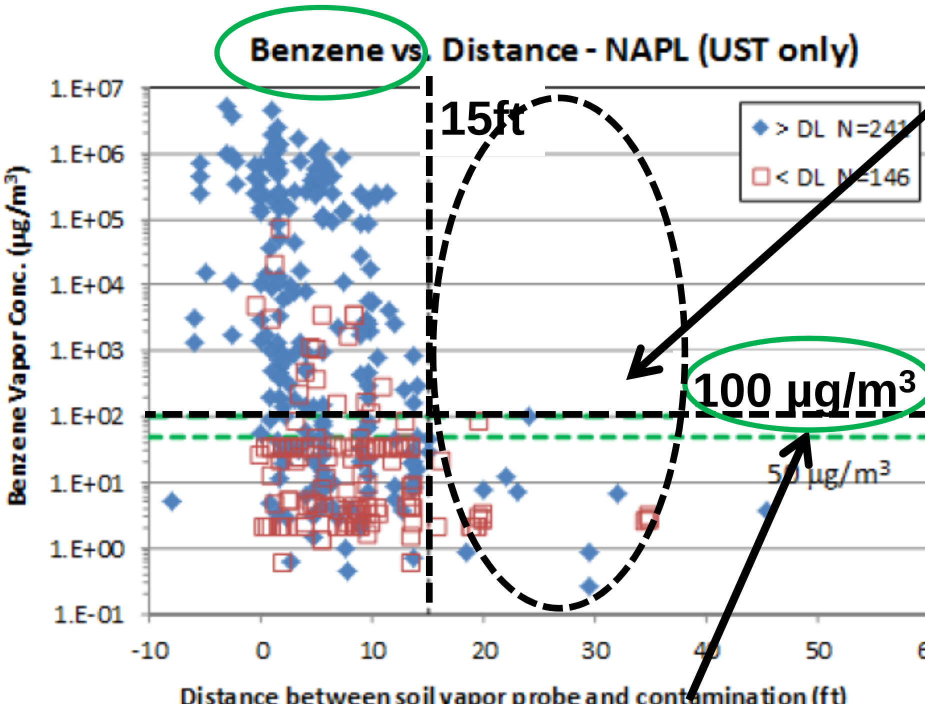
Petroleum Vapor Intrusion *SEMI-FACTS

- ***Free product*** **in vadose-zone soil or on groundwater required to pose significant PVI risks;**
- **Small *de minimis volumes* of contaminated soil (e.g., 10 cyds?) or small areas of free product on groundwater (e.g., <100ft^2?) do not pose significant, *long-term* PVI risks, regardless of concentrations (not discussed in USEPA or ITRC PVI documents);**
- **Vapors unlikely to exceed potential PVI levels of concern greater than *15-30ft* from the source ("Vertical Separation Distance");**
- **"Lateral Separation Distance" default = 100ft.**

***General agreement between HDOH, USEPA & ITRC guidances**

USEPA Vertical (Separation) Method

LNAPL Source UST/AST Sites



Benzene Vertical Separation Distance

- **Problem: <u>MINIMAL DATA POINTS Beyond 15ft!!</u>**
- How did they conclude that benzene vapors >100 µg/m³ won't migrate >15ft from source?
- Looked at 0-15ft trends from source (not clearly discussed in USEPA or ITRC PVI documents).
- Appears adequate for use in Hawai'i

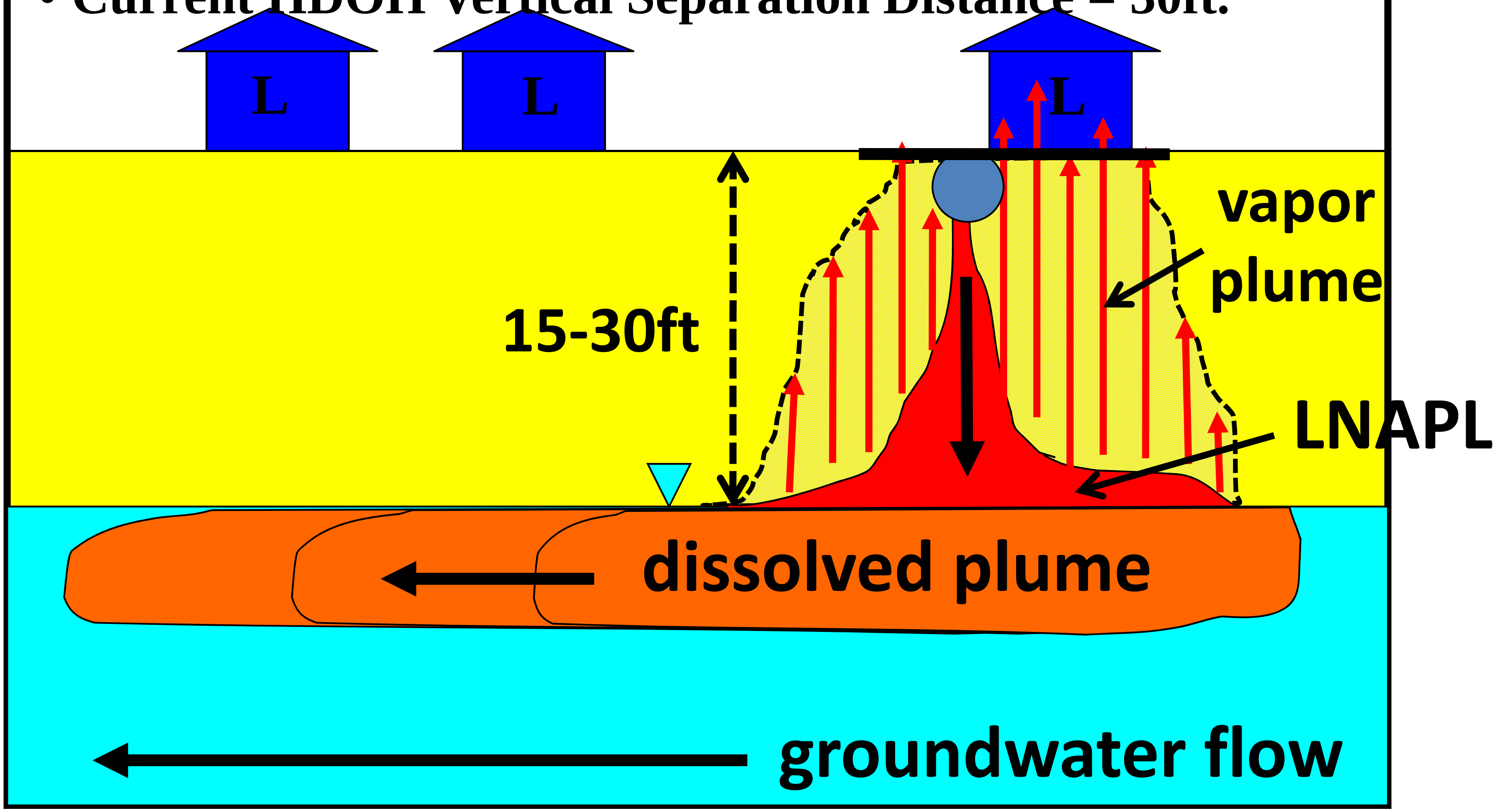
Subslab PVI screening level = 100 µg/m³ (HDOH = 310 µg/m³)
Assumes subslab attenuation factor of 0.003 (reasonable for cold climates).

KEY POINTS

- **Vertical screening distance = 15 feet for LNAPL UST/AST sites (18 feet industrial sites)**
- **Benzene requires the greatest distance to attenuate**

Additional PVI Considerations

- Much smaller vapor plumes than chlorinated solvents;
- Primary risk from shallow free product and anaerobic buildup of vapors under structures;
- Current HDOH Vertical Separation Distance = 30ft.



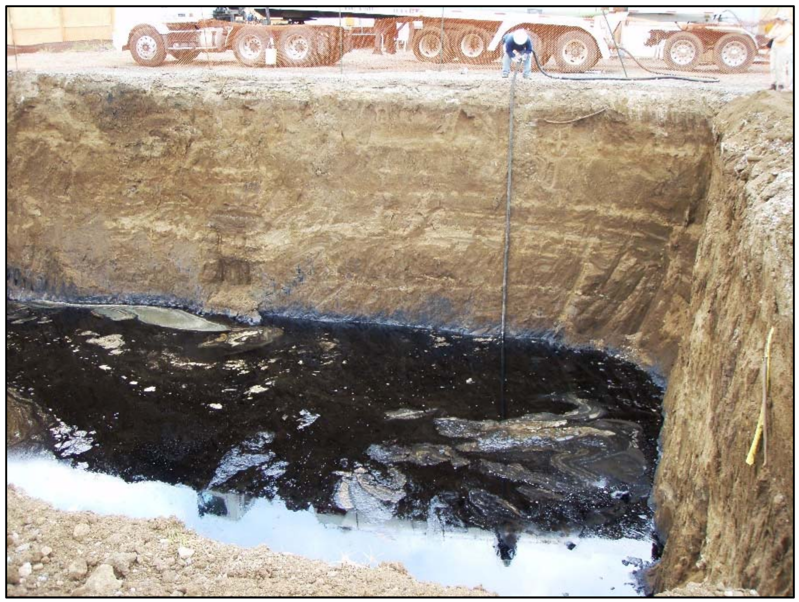
Petroleum Vapor Intrusion *FALLACIES

1. Diesel fuel is not volatile and does not pose a PVI risk (Hint: If you can smell it then it's volatile);
2. Risk-based indoor air and soil gas action (screening) levels cannot be developed for the non-BTEXN, Total Petroleum Hydrocarbons (TPH) component of vapors;
3. Benzene or other individual aromatics always drive PVI risks over TPH;
4. TPH compounds in vapors will not migrate >2-3ft from source above potential levels of concern for PVI (vs 15ft for benzene).

***Common past misconceptions still sometimes mentioned in PVI workshops**

Fallacy #1: Diesel Fuel is Not Volatile

1. Diesel fuel is not volatile and does not pose a PVI risk (Hint: If you can smell it then it's volatile).



- **Diesel included as a potential PVI concern in USEPA 2015 PVI guidance;**
- **Implied to not be sufficiently volatile for potential PVI concerns in 2014 ITRC guidance.**

HDOH Field Study: Chemistry and Toxicity of Petroleum Vapors

- **Soil vapor samples collected at five sites on O'ahu;**
- **Focus on jet fuels and diesel (supplement to USEPA PVI database for gasoline sites);**
- **Reviewed other published data (including PVI database);**
- **Results discussed in Appendix C of 2014 ITRC PVI guidance.**

***Field Investigation of the Chemistry and Toxicity of TPH in Petroleum Vapors, Implications for Potential Vapor Intrusion Hazards (December 2012)*: Hawai'i Department of Health, HEER, http://www.hawaiidoh.org/**

Brewer et al, 2013, *Risk-Based Evaluation of Total Petroleum Hydrocarbons in Vapor Intrusion Studies*: International Journal of Environmental Research and Public Health, Volume 10, pp 2441-2467. http://www.mdpi.com/1660-4601/10/6/2441/

Soil Vapor Sample Collection

Summa Canisters (C5-C12)

Sorbent Tubes (C12-C18)

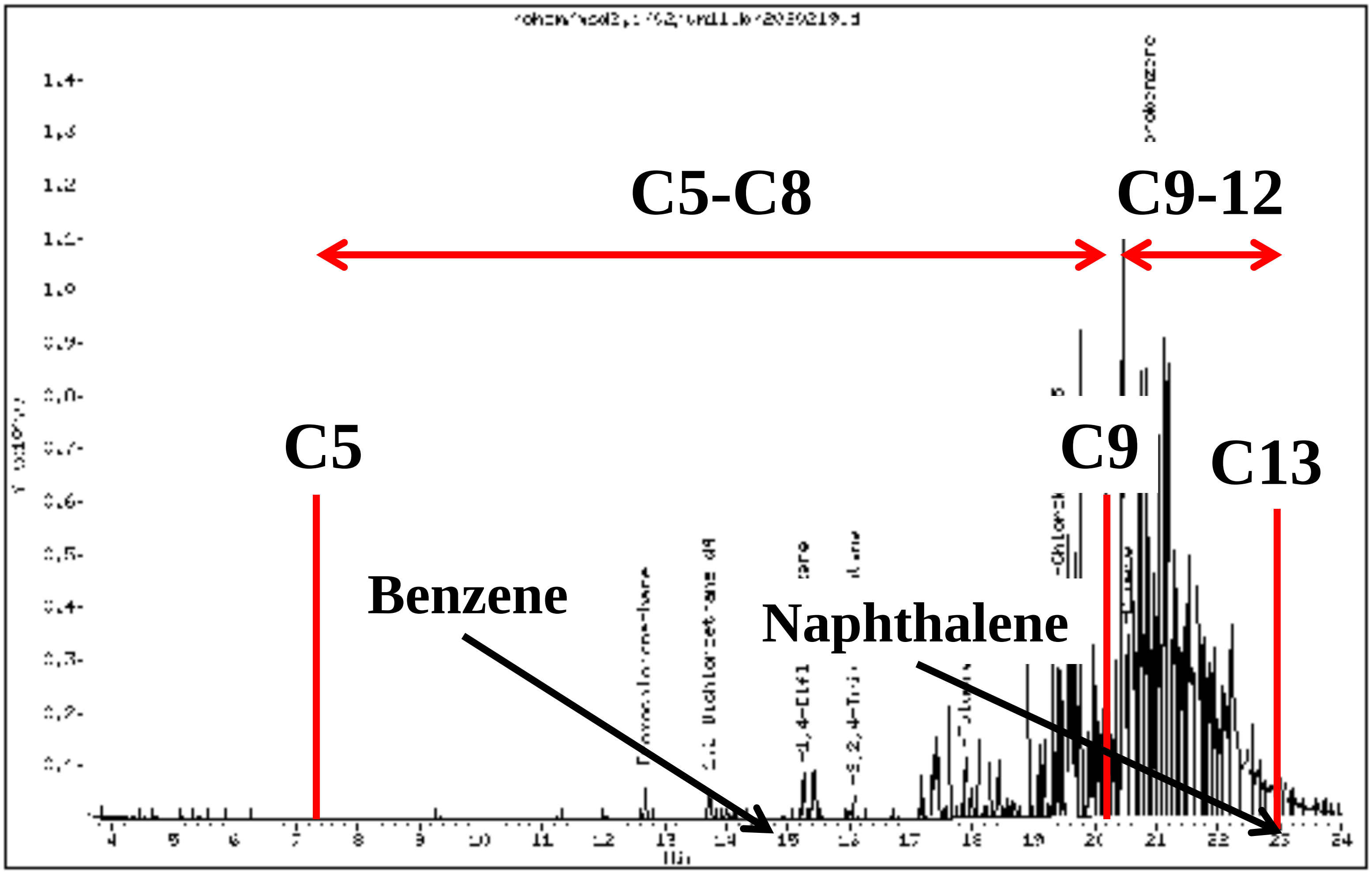
- **Most samples collected 5 to 15+ft from source;**
- **Each Sample:**
  - **TPH (total), TPH carbon ranges, BTEXN;**
  - **Calculated weighted TPH toxicity factor;**
  - **TPH to Benzene ratio (assess risk driver).**

TPH Dominates BTEXN in Vapors

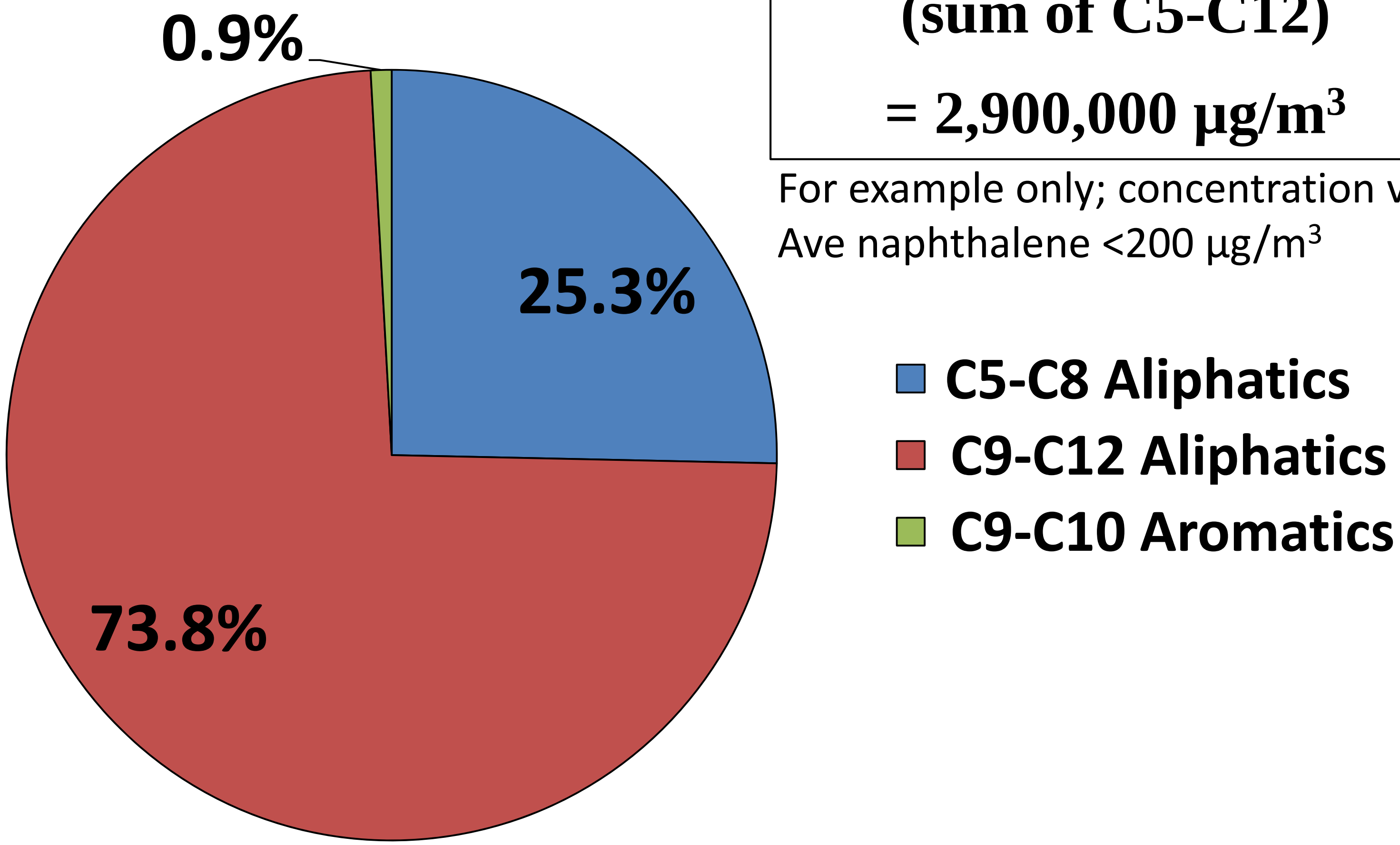
Site/Fuel Type	Average Soil Gas Composition		
	[1]TPH	[2,3]BTEXN	TPH:Benzene
[1]USEPA PVI Database (mostly gasoline)	>95% (estimate)	<5% (estimate)	300:1 (median)
Site A: (mostly AVGAS)	99.6%	0.4%	1,500:1
Site D: (mostly JP-4)	98.3%	1.7%	9,000:1
Site E: (mostly diesel)	99.9%	0.1%	19,000:1

1. Total Petroleum Hydrocarbons, excluding BTEXN.
2. Toluene, ethylbenzene, xylenes and naphthalene data not consistently included; TPH:Benzene ratio highly variable between samples (5:1 to >450,000:1).
3. Total BTEXN normally dominated by xylenes.

Gas Chromatograph of Diesel Soil Vapors (Study Site E)



Study Site E TPH Carbon Range Makeup
(diesel)



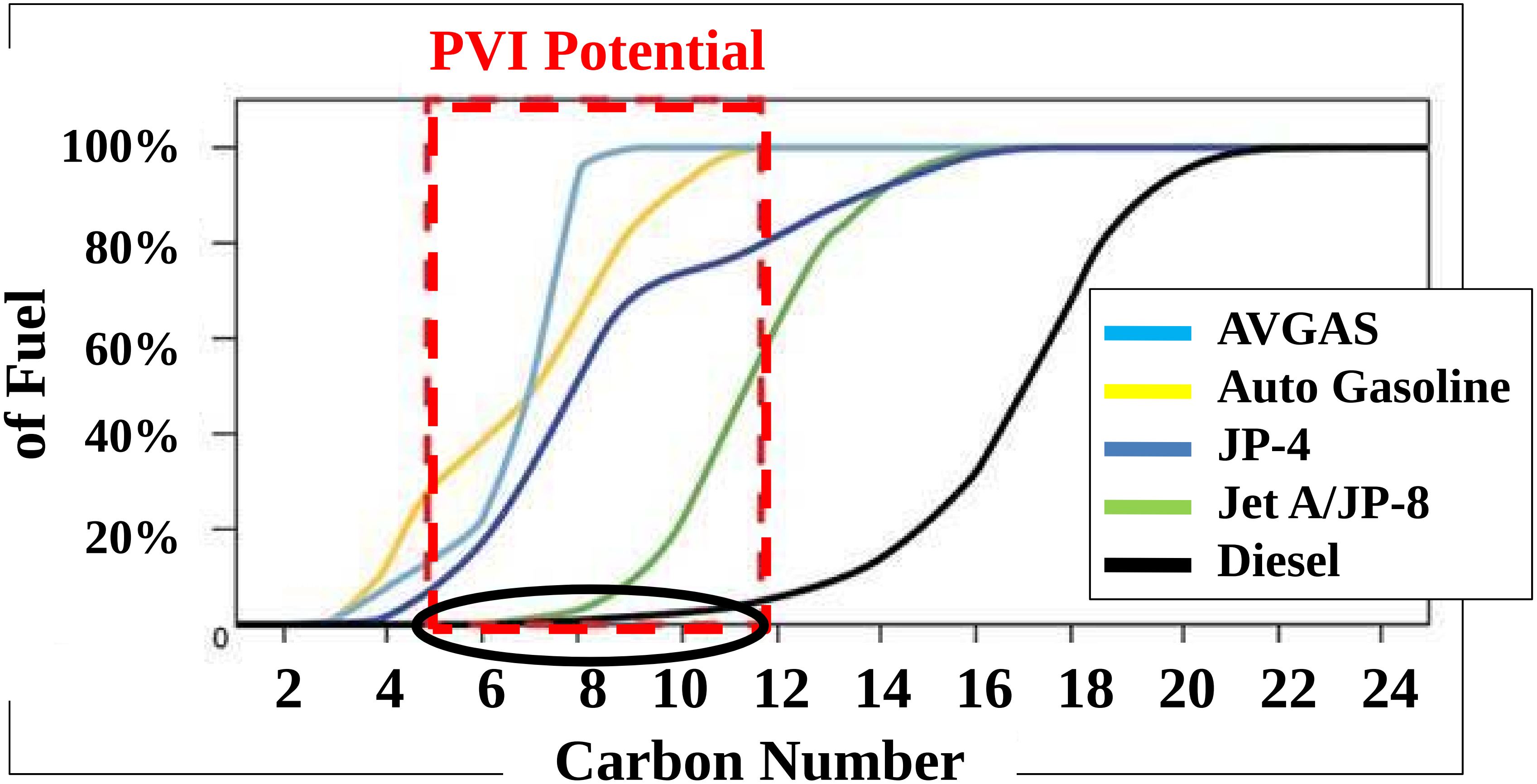
Average TPH in Soil Gas (sum of C5-C12)

= 2,900,000 µg/m^3

For example only; concentration varies
Ave naphthalene <200 µg/m^3

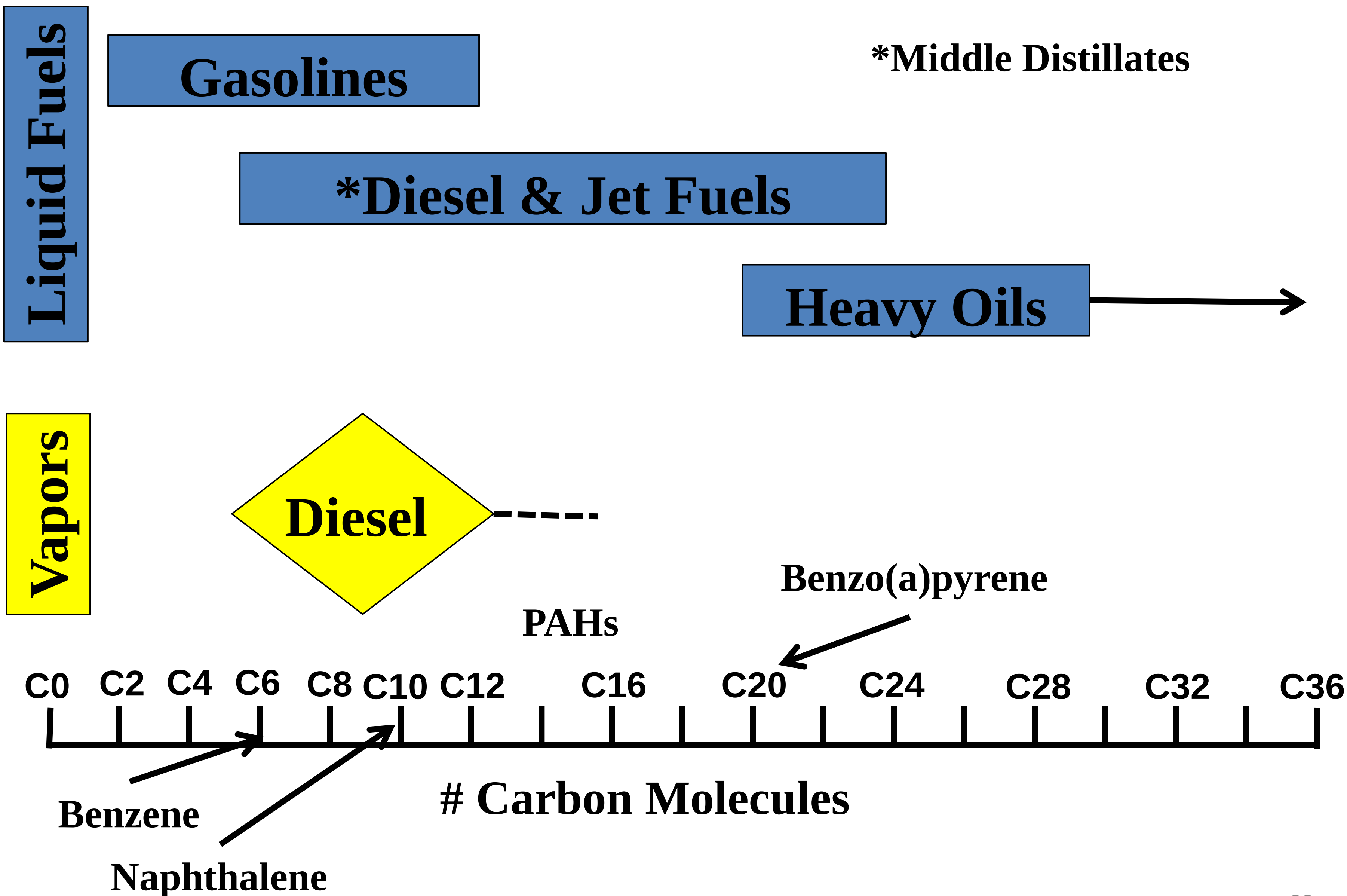
Based on TO-15 Summa Data

Small but Important Component of Diesel Fuel
(after ITRC 2014)



- C5-C12 component of diesel generates vapor plume;
- TPH vapors high enough concentrations to pose PVI risks;
- Important to ask lab to report TPH in air or soil vapors as sum of C5-C12+ for <u>all</u> fuel types (not “TPHg” or “TPHd”).

Chemistry of Liquid Fuels vs Vapors



Diesel is Volatile

- **Significant vapors from diesel and other middle distillates;**
- **Dominated by C9-C12 TPH aliphatics;**
- **Lower TPH concentrations compared to gasoline;**
- **Potential PVI risks from shallow (<15ft) free product;**
- **Naphthalene was typically ND or very low and not a risk driver at study sites.**

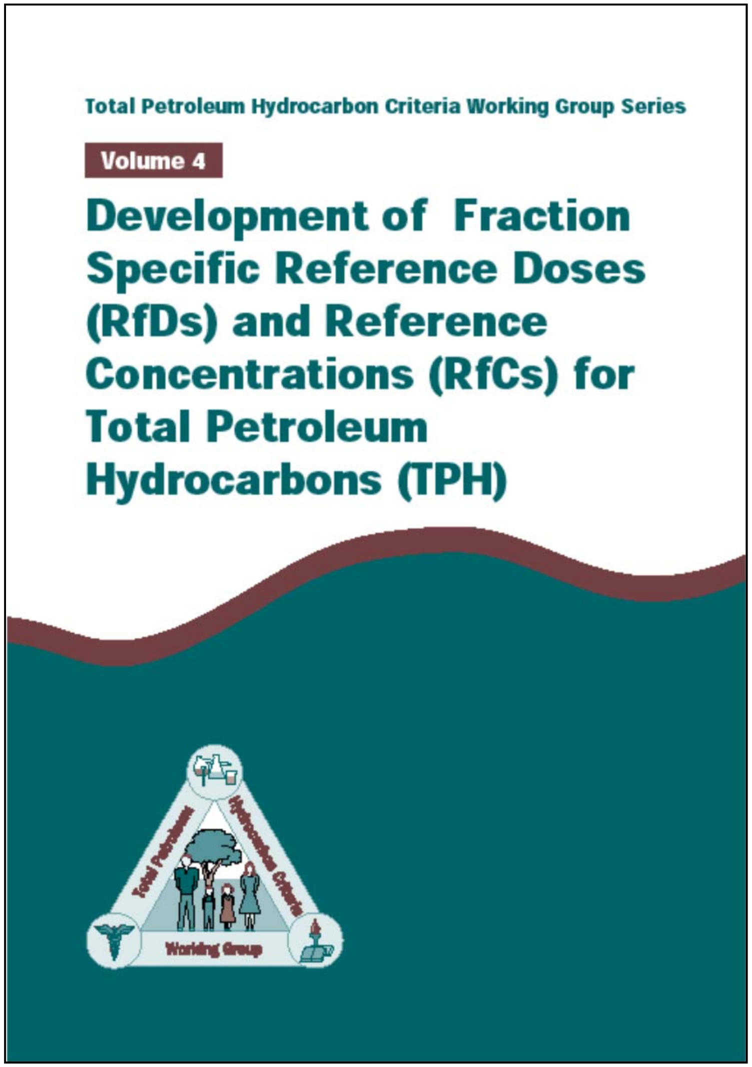
PID Factoid (low readings at site):

- **PIDs respond primarily to aromatics;**
- **Poor response to aliphatic-only vapor plumes.**

Fallacy #2: No TPH Action Levels for PVI

2. **Risk-based indoor air and soil gas action (screening) levels cannot be developed for the non-BTEXN, Total Petroleum Hydrocarbons (TPH) component of vapors.**

Toxicity of Total Petroleum Hydrocarbons TPH Working Group (mid/late 1990s)



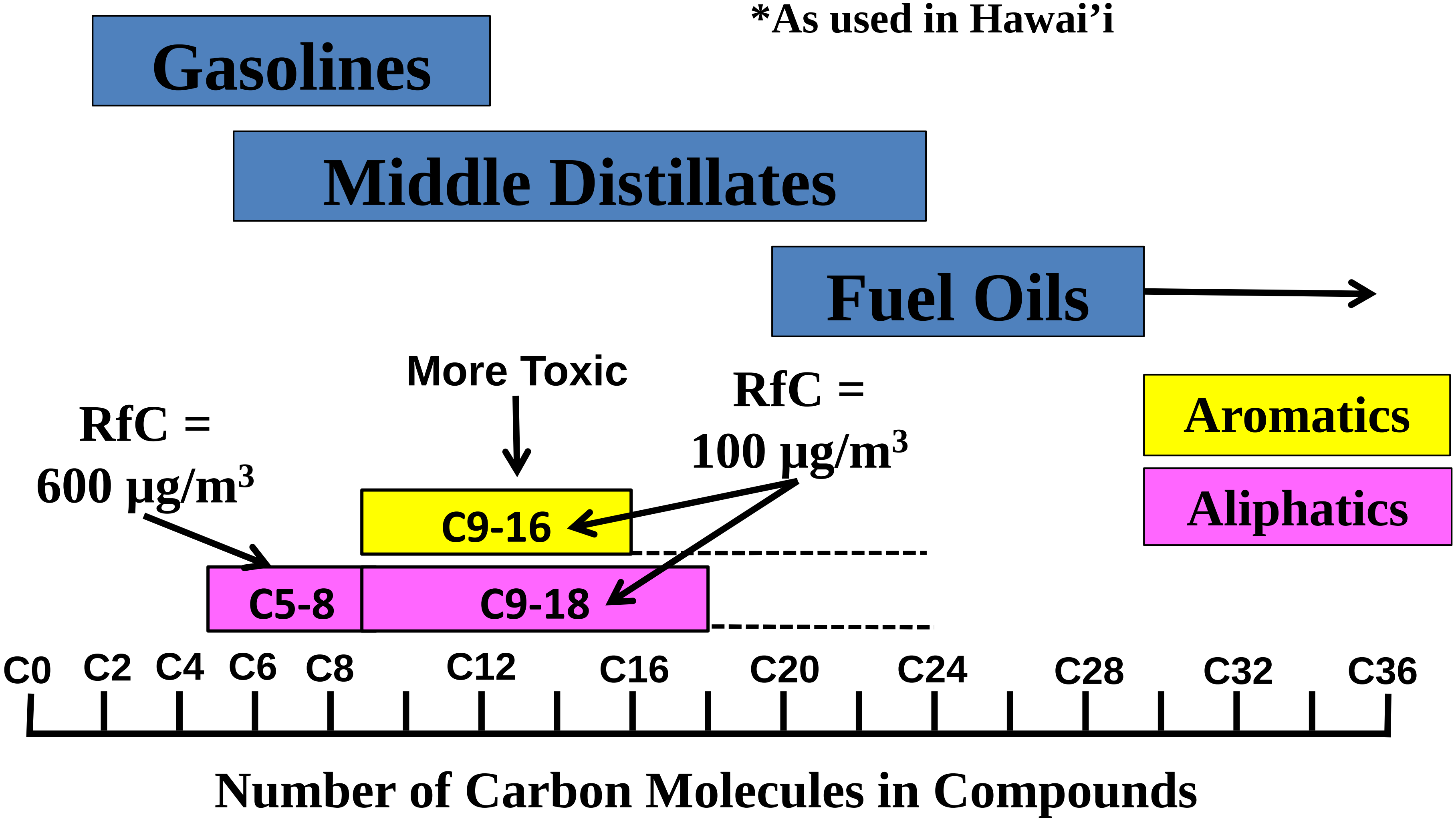
<u>Published TPH Toxicity Factors</u>

- **Massachusetts DEP (1997+)**
- **USDHHS (1999)**
- **Washington DOE (2006)**
- **California EPA (DTSC 2009)**
- **USEPA (2009)**

- **Several states publish risk-based screening levels for TPH (mostly for soil);**
- **Only California and Hawai'i have TPH indoor air and soil gas screening levels for PVI?**

*USEPA Inhalation Toxicity Factors for Vapor-Phase Carbon Ranges

*As used in Hawai'i



TPH = Sum of Aliphatics + non-BTEXN Aromatics

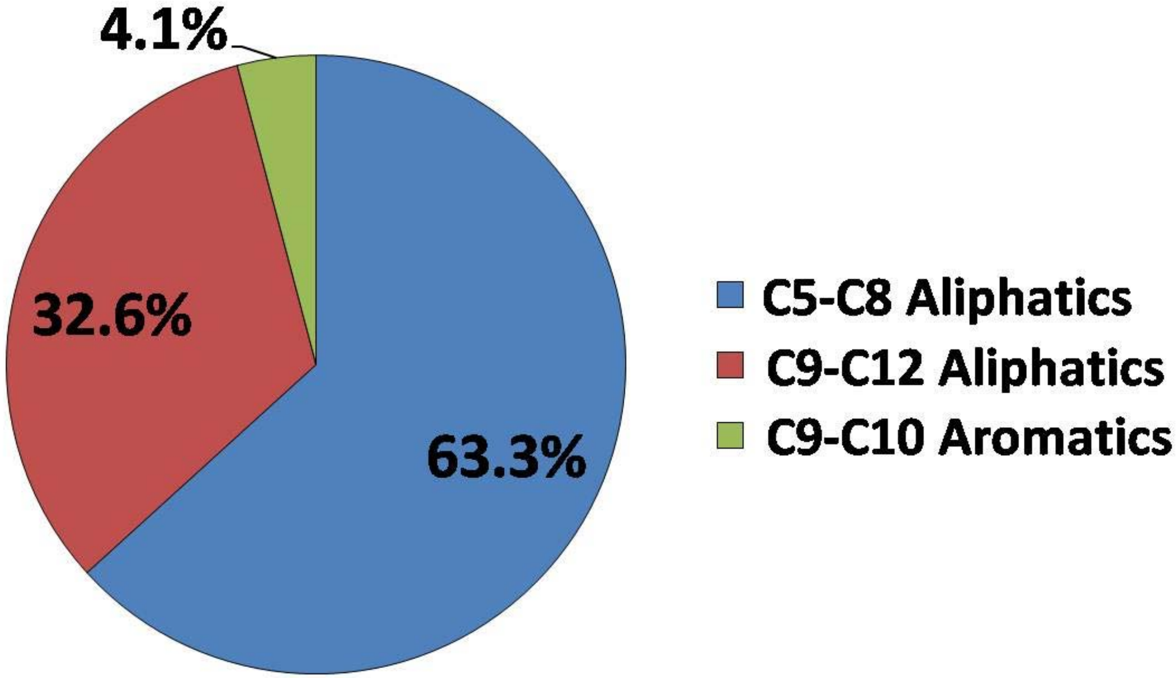
TPH Carbon Range Action Levels

Carbon Range	[1]Inhalation RfC ($\mu g/m^3$)	[2]Indoor Air ($\mu g/m^3$)	[3]Subslab Soil Gas ($\mu g/m^3$)
C5-C8 Aliphatics	600	630	630,000
C9-C18 Aliphatics	100	100	100,000
C9-C16 Aromatics	100	100	100,000

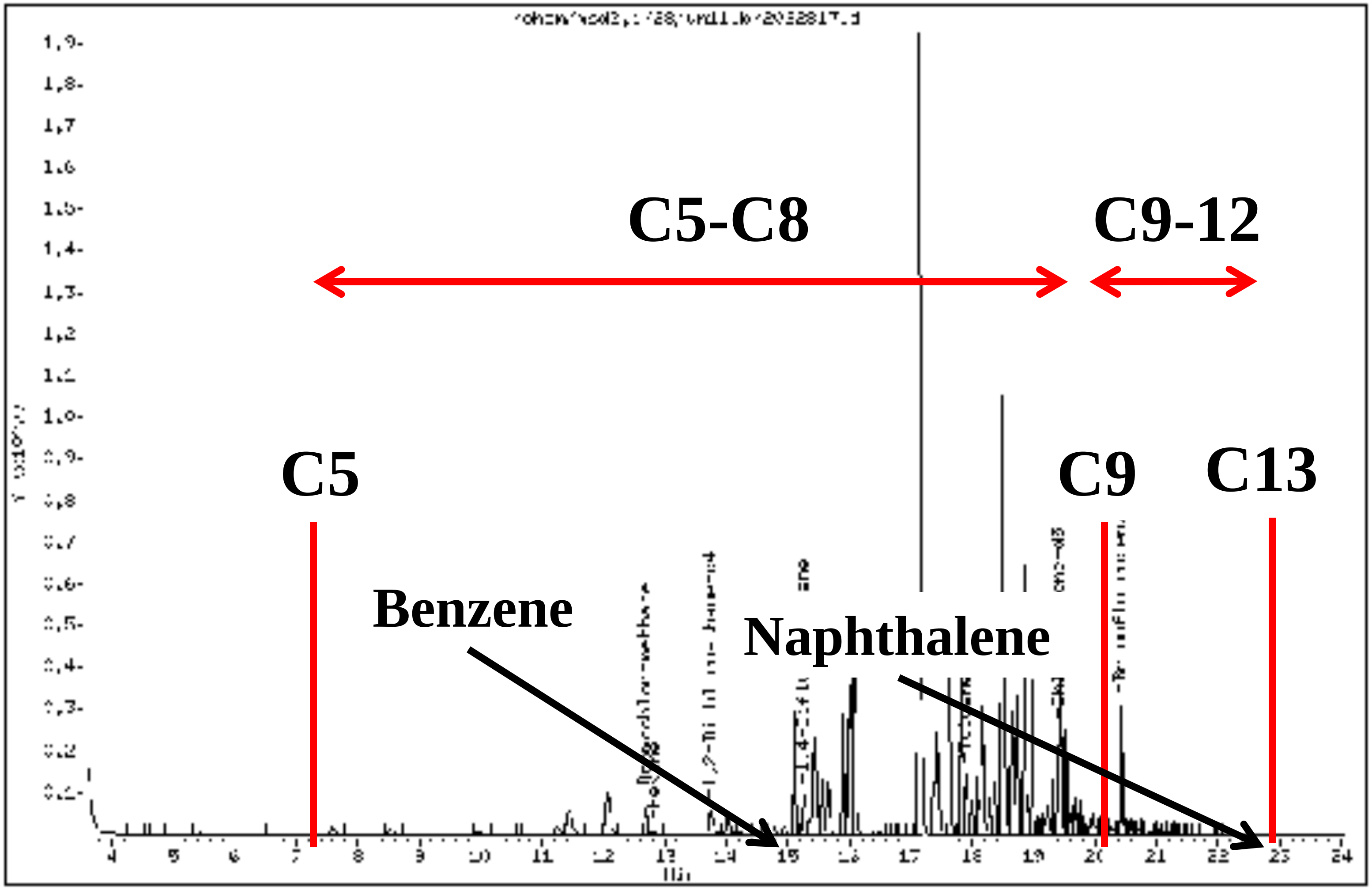
1. After USEPA 2009; variably aromatic RfCs presented.
2. Residential exposure (see also USEPA Regional Screening Levels).
3. Assumes 1/1,000 vapor attenuation factor.

Weighted Indoor Air & Soil Gas TPH Action Levels

- **Calculate site-specific, weighted Inhalation Reference Concentration based on TPH carbon range makeup (see Brewer et al, 2013);**
- **Reduces need for site carbon range data ($$$)**
- **Use default carbon range makeup for generic screening levels.**



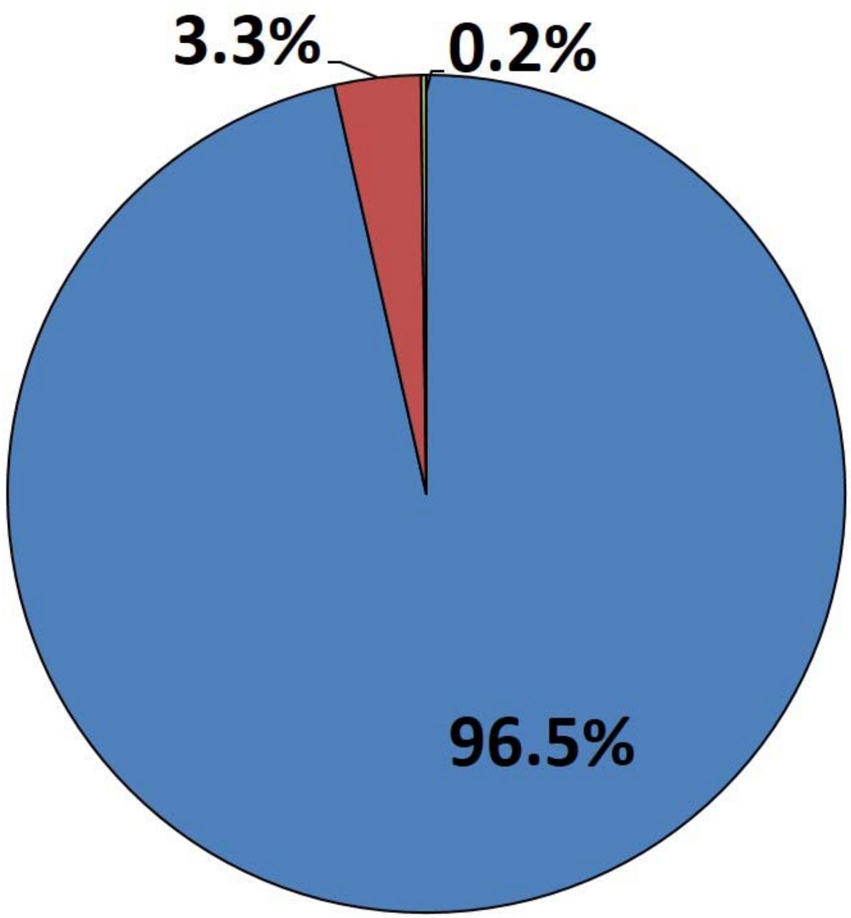
Gas Chromatograph of AVGAS Soil Vapors (Study Site A)



Weighted TPH Action Levels for AVGAS Soil Vapors (Site A)

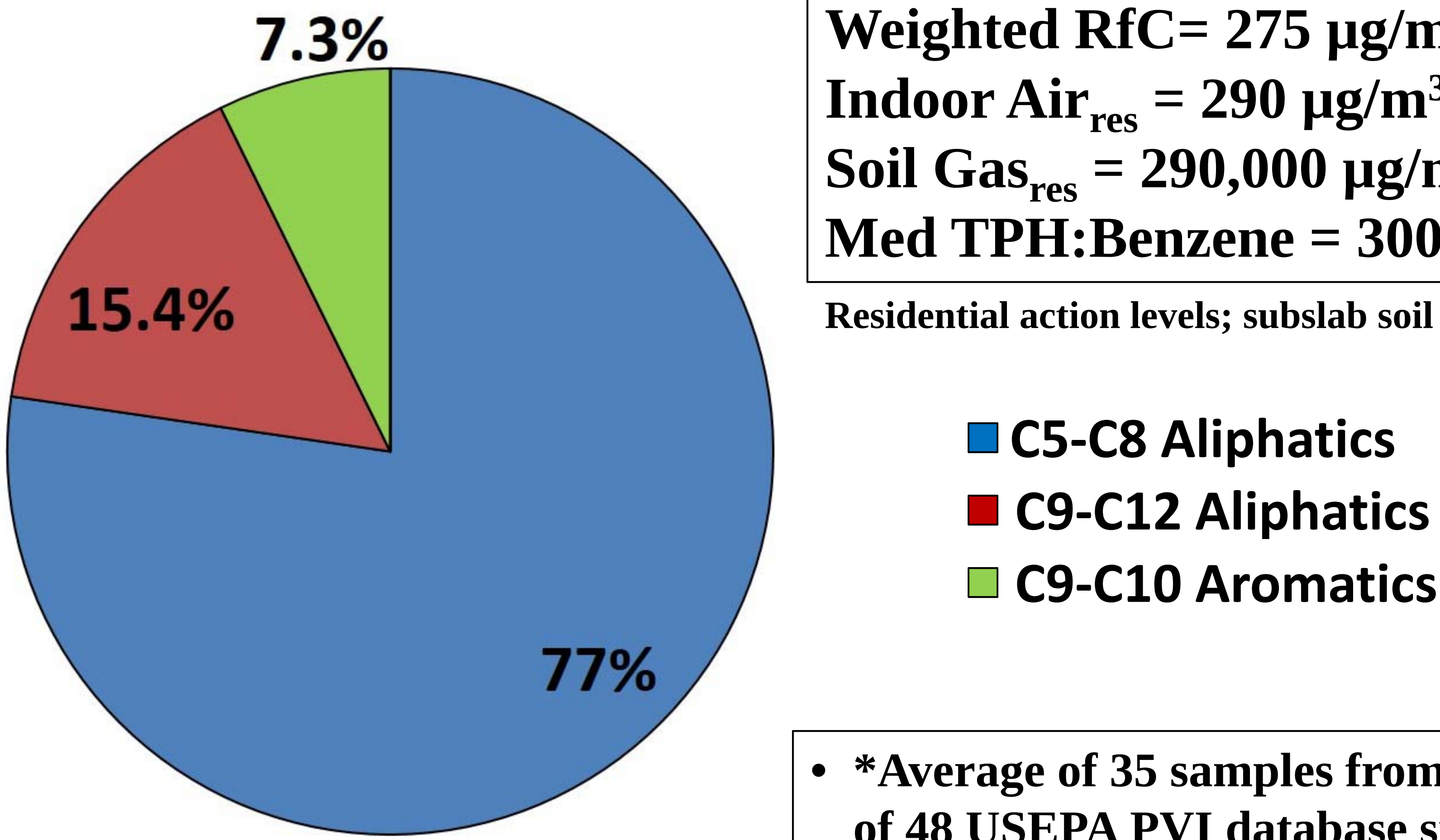
Weighted RfC= 510 µg/m^3
Indoor Air$_{res}$ = 530 µg/m^3
Soil Gas$_{res}$ = 530,000 µg/m^3
Ave TPH:Benzene = 1,500:1

Residential action levels; subslab soil gas



Based on TO-15 Summa Data

*Weighted TPH Action Levels for Gasoline Soil Vapors (average of USEPA PVI Database)

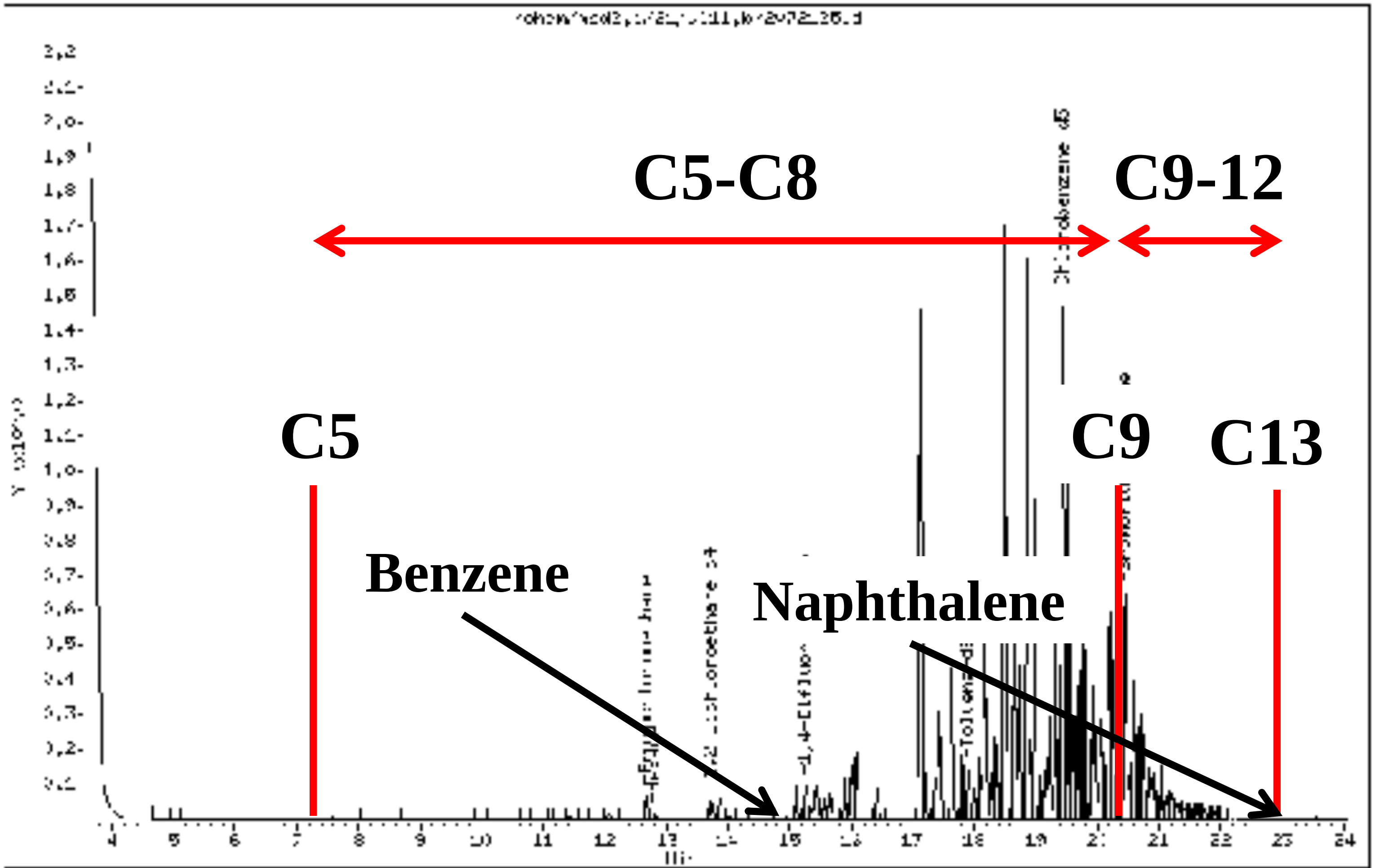


Weighted RfC= 275 µg/m^3
Indoor Air$_{res}$ = 290 µg/m^3
Soil Gas$_{res}$ = 290,000 µg/m^3
Med TPH:Benzene = 300:1

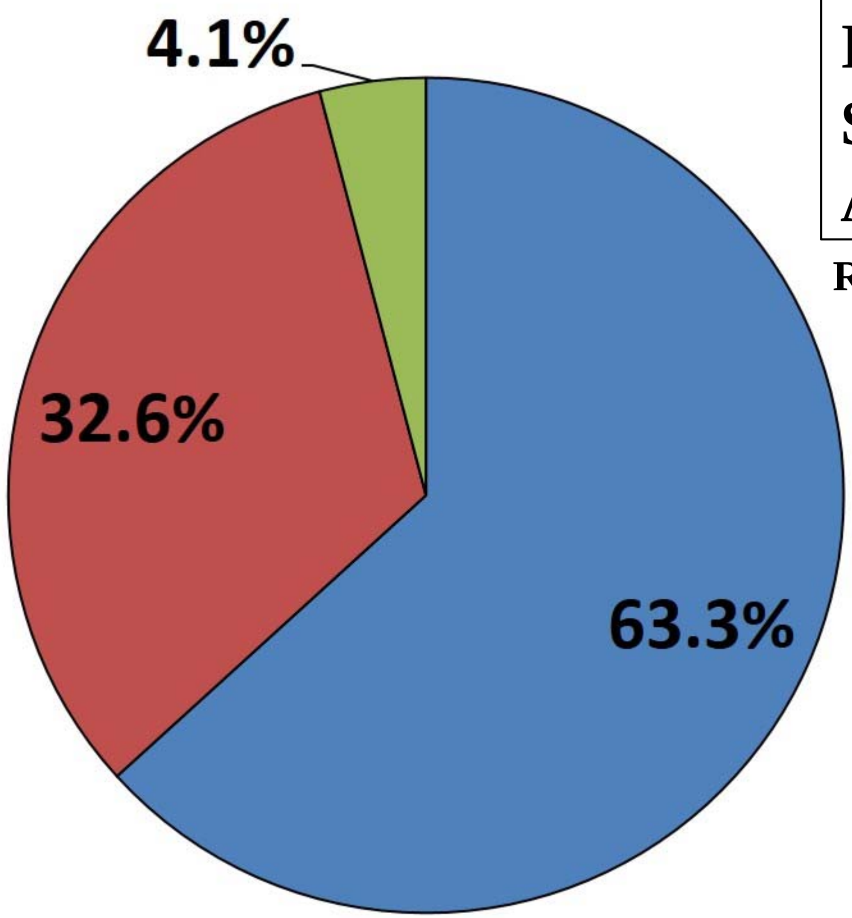
Residential action levels; subslab soil gas

- ***Average of 35 samples from 10 of 48 USEPA PVI database sites;**
- **Mix of diesel or kerosene vapors at some sites (high C9-C12 aliphatics)?**

Gas Chromatograph of JP-4 Soil Vapors (Study Site D)



Weighted TPH Action Levels for JP-4 Soil Vapors (Site D)

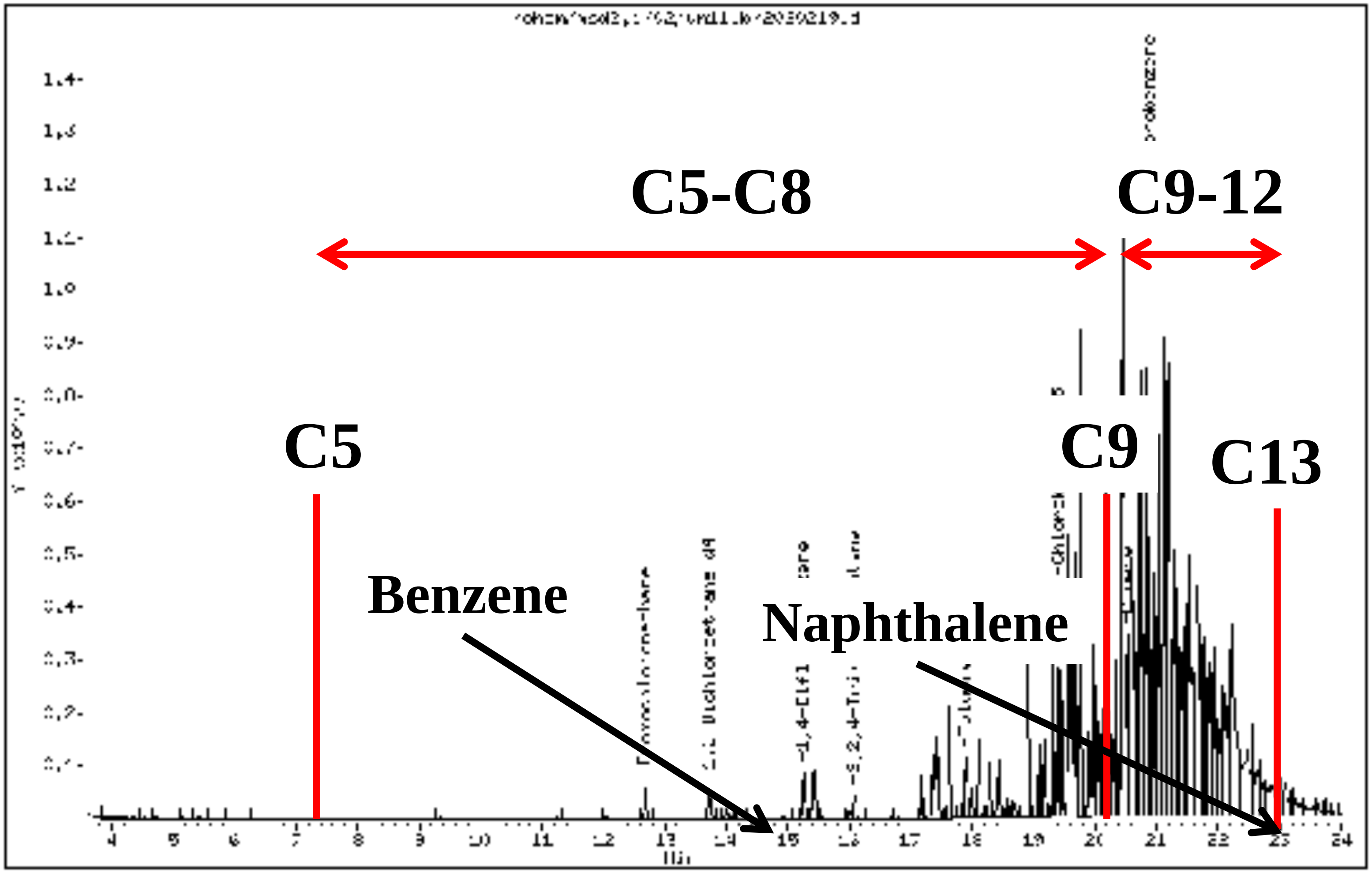


Weighted RfC= 211 µg/m^3
Indoor Air$_{res}$ = 220 µg/m^3
Soil Gas$_{res}$ = 220,000 µg/m^3
Ave TPH:Benzene = 9,100:1

Residential action levels; subslab soil gas

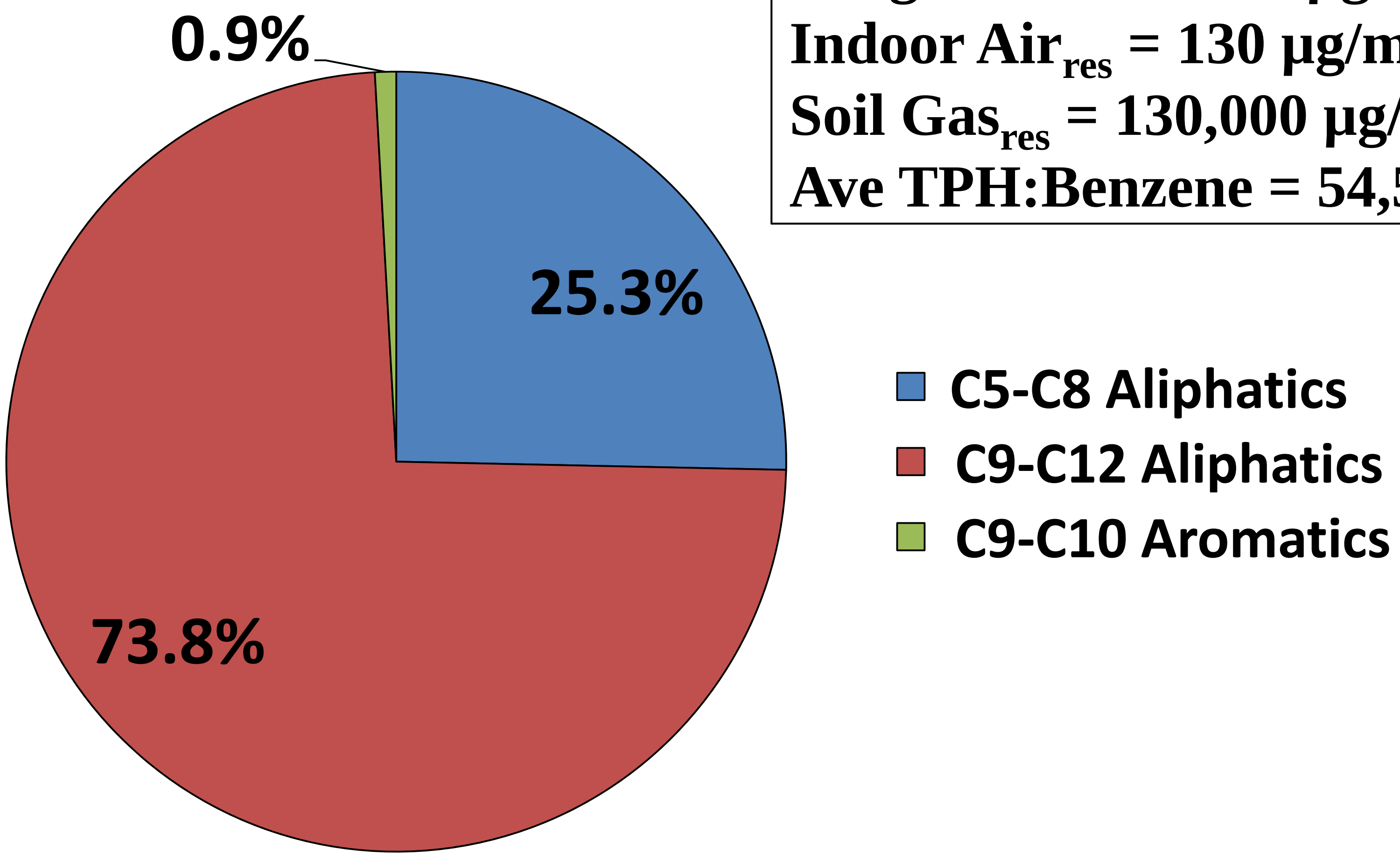
Based on TO-15 Summa Data

Gas Chromatograph of Diesel Soil Vapors (Study Site E)



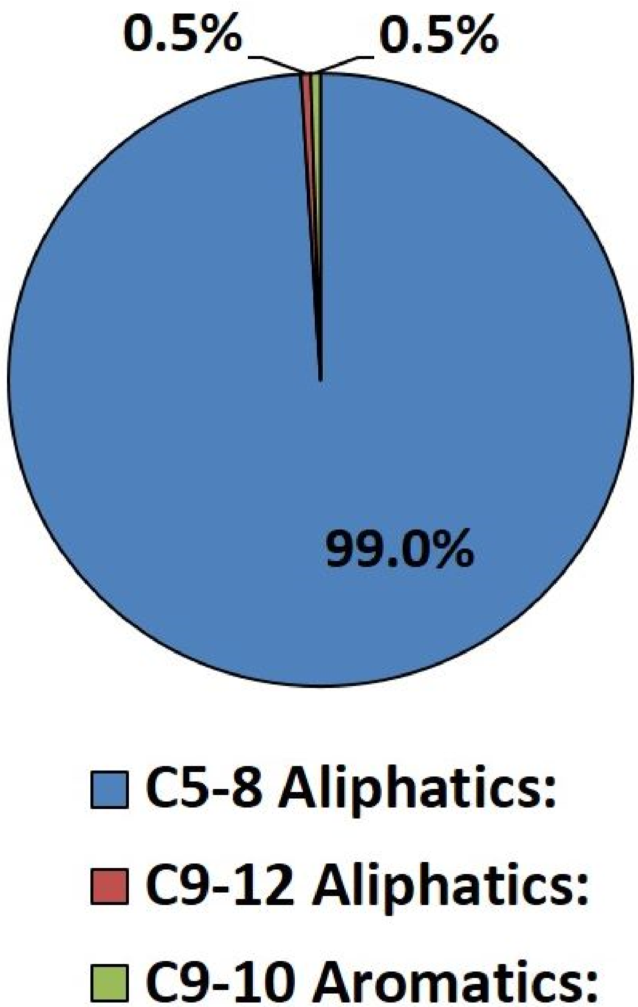
Weighted TPH Action Levels for Diesel Soil Vapors (Site E)

Weighted RfC= 127 µg/m^3
Indoor Air$_{res}$ = 130 µg/m^3
Soil Gas$_{res}$ = 130,000 µg/m^3
Ave TPH:Benzene = 54,500:1



Based on TO-15 Summa Data

Default HDOH TPH Action Levels – Gasoline Vapors
(based on published data, including Biovapor 2010, etc.)



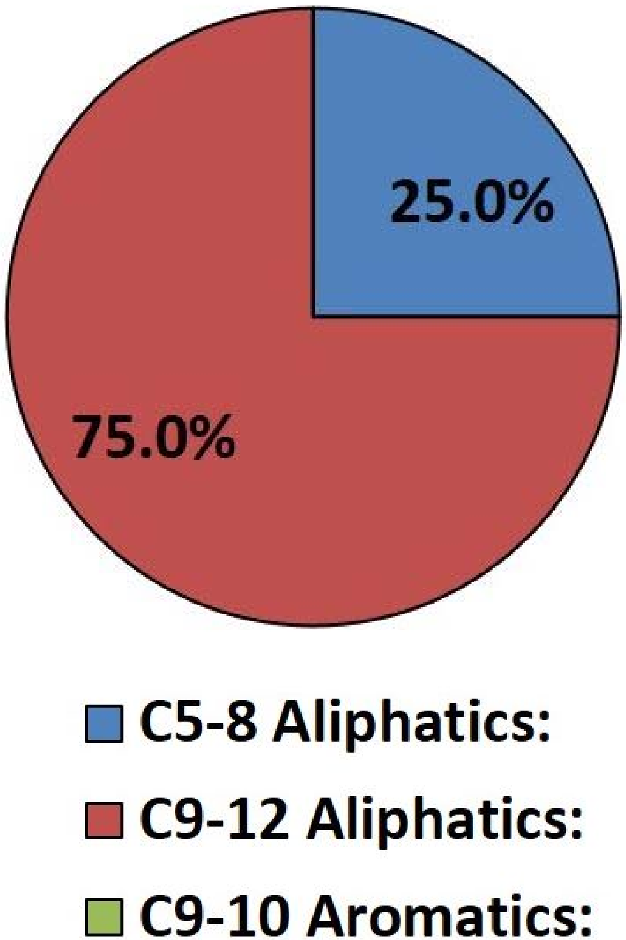
***Weighted RfC= 571 ug/m^3**
Indoor Air_{res} = 600 ug/m^3
Soil Gas_{res} = 600,000 ug/m^3

Residential action levels noted; subslab soil gas

- **Vapors dominated by lower-toxicity, C5-C8 aliphatics;**
- **Minor heavier aliphatics and aromatics.**

Gasoline Odor Recognition Threshold:
0.2 to 1.0 ppmv (750 to 4,000 ug/m^3)

Default TPH Action Levels – Diesel Vapors
(based on 2012 HDOH field study and published data)



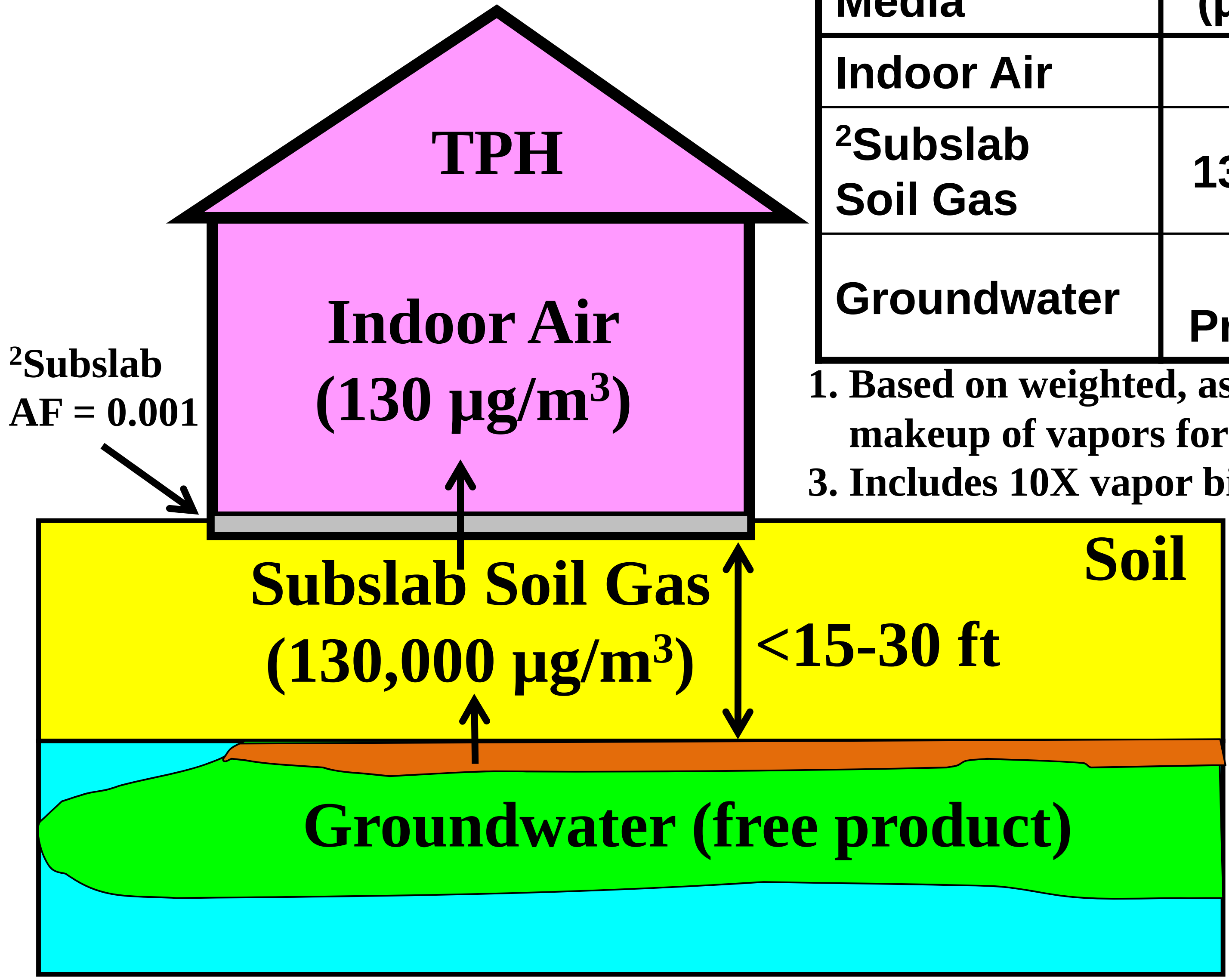
***Weighted RfC= 126 ug/m^3**
Indoor Air$_{res}$ = 130 ug/m^3
Soil Gas$_{res}$ = 130,000 ug/m^3

Residential action levels noted; subslab soil gas

- **Dominated by higher-toxicity C9-C12 aliphatics;**
- **Used as default in HDOH vapor intrusion guidance;**
- **Apparent mix of gasoline and diesel vapors common at many petroleum sites.**

Diesel Odor Recognition Threshold:
0.5 to 1.0 ppmv (3,500 to 7,000 ug/m^3)

HDOH Default TPH PVI Action Levels



Media	[1]TPH (µg/m³)	Benzene (µg/m³)
Indoor Air	130	0.31
[2]Subslab Soil Gas	130,000	310
Groundwater	Free Product	[3]1,900

1. Based on weighted, assumed carbon range makeup of vapors for diesel.
3. Includes 10X vapor biodegradation factor.

Fallacy #3: Just Check the Benzene…

3. Benzene or other individual aromatics always drive PVI risks over TPH.

- No specific discussion of PVI risk drivers in either the USEPA or the ITRC guidance documents;
- Focus on benzene examples in documents and training workshops does not imply that that TPH (or other VOCs) can be ignored.

Determining the PVI "Risk Driver"

- **Risk Driver = No significant risk from other chemicals when risk posed by this chemical is addressed;**
- **Example:**
  - **Soil contaminated with high concentrations of lead and very low concentrations of dioxins;**
  - **Cleanup to meet lead action levels also addresses dioxin contamination;**
  - **Cleanup to meet dioxin action levels only does not fully address lead contamination;**
  - **Lead is the "risk driver";**
- **Could TPH in vapors still pose a PVI risk when benzene action level is met (i.e., can TPH "drive risk" over benzene)?**
- **At some ratio of TPH to Benzene TPH will begin to be the main risk driver.**

TPH:Benzene "Critical Threshold Ratio" (generic or site-specific)

$$\text{Critical Threshold Ratio} = \frac{\text{TPH Action Level}}{\text{Benzene Action Level}}$$

Default HDOH TPH:Benzene CTR

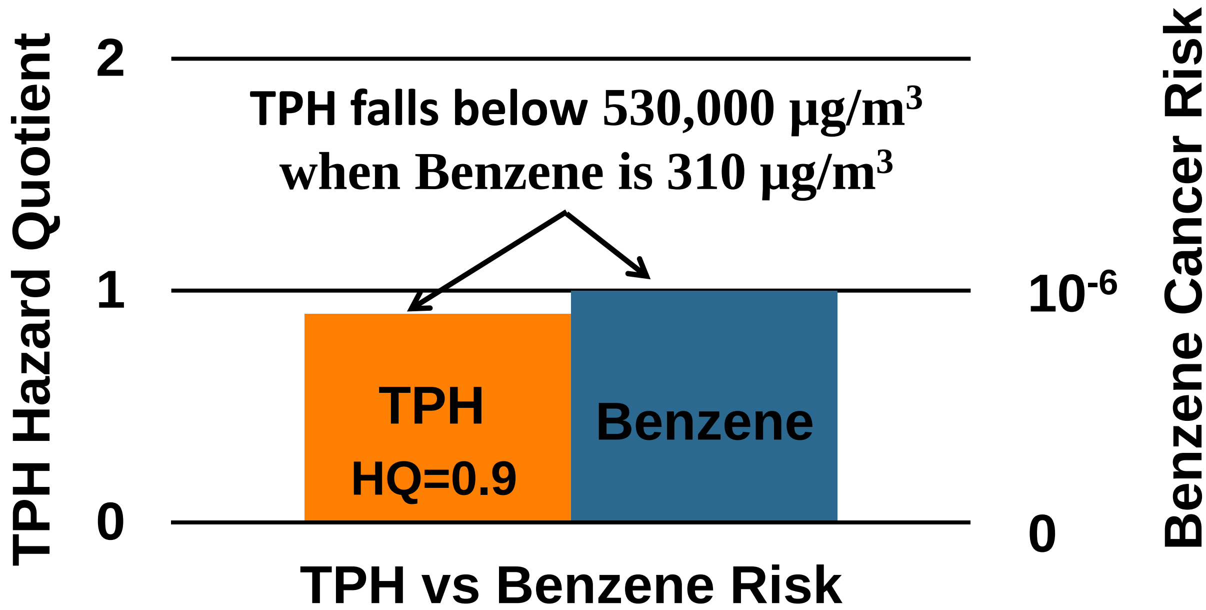
Media	[1]TPH Action Level (µg/m^3)	[2]Benzene Action Level (µg/m^3)	TPH:Benzene Critical Ratio
Indoor Air	130	0.31	420:1
Subslab Soil Gas	130,000	310	

1. HDOH default; based on noncancer HQ = 1 (collect TPH carbon range data to develop site-specific TPH action levels);
2. Based on 10^{-6} excess cancer risk.

Begin considering TPH as potential PVI risk driver when site-specific TPH:Benzene ratio >420:1

Site A PVI Risk Driver (AVGAS)

Critical TPH:Benzene Ratio = 1,710:1
Average Measured TPH:Benzene Ratio= 1,513:1

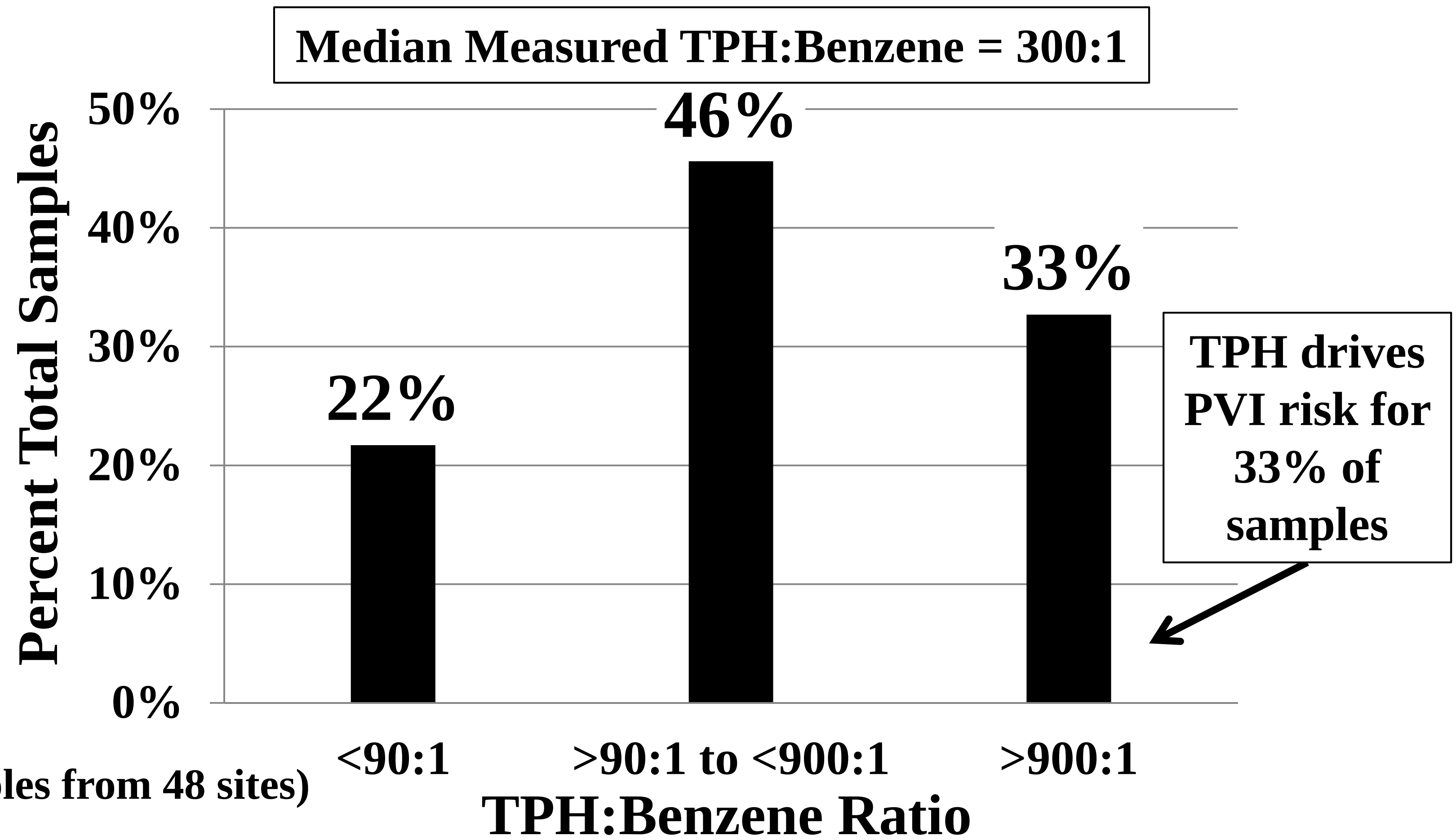


Based on TO-15 Summa Data

Benzene adequate to evaluate vapor intrusion hazards *provided that a target 10^{-6}* cancer risk is used.
(TPH noncancer HQ<1 when benzene risk = 10^{-6})

USEPA PVI Database Risk Drivers (gasoline sites)

$$\text{TPH:Benzene Critical Threshold Ratio} = \frac{290\ \mu g/m^3}{0.31\ \mu g/m^3} = 900:1$$

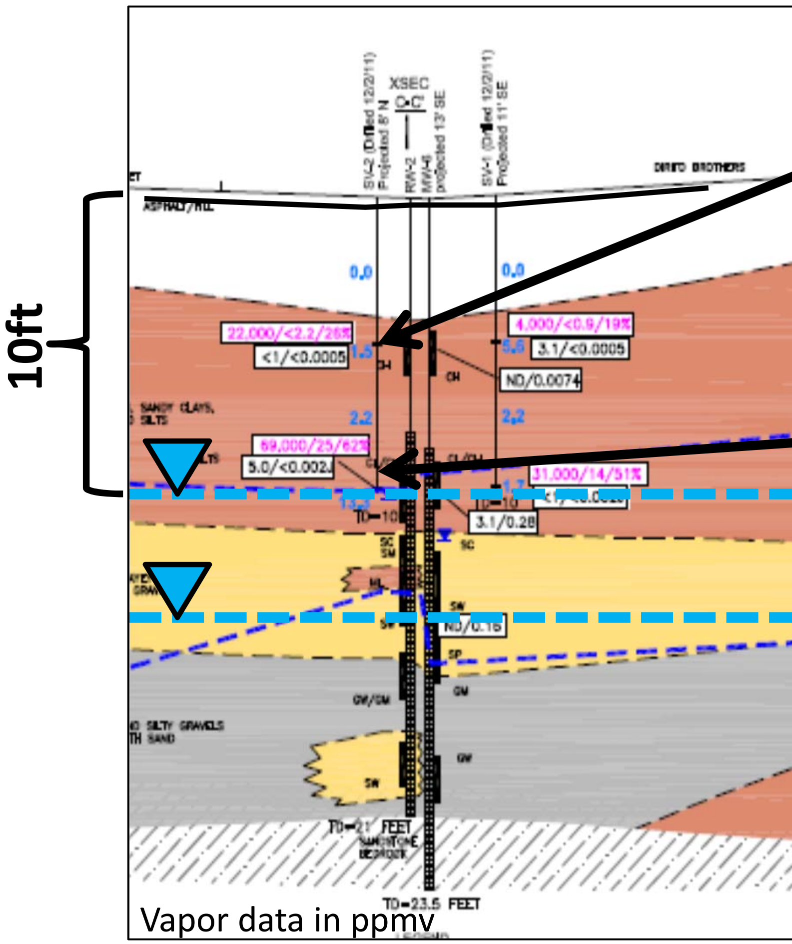


(364 samples from 48 sites)

- TPH noncancer HQ>1 possible for 79% of samples even when benzene risk = 10^{-5};
- Suggests important to use 10^{-6} benzene cancer risk for PVI screening and remediation.

Example Gasoline Site in California (Part 1)

- Groundwater-only source (low-benzene gasoline);
- Carbon range makeup: 80% C5-C8, 20% C9-C12
- TPH RfC = 308 μg/m^3 (indoor air screening level = 320 μg/m^3);
- Critical TPH:Benzene Ratio = 1,000:1 (320 μg/m^3/0.31μg/m^3);
- TPH PVI risks over benzene.



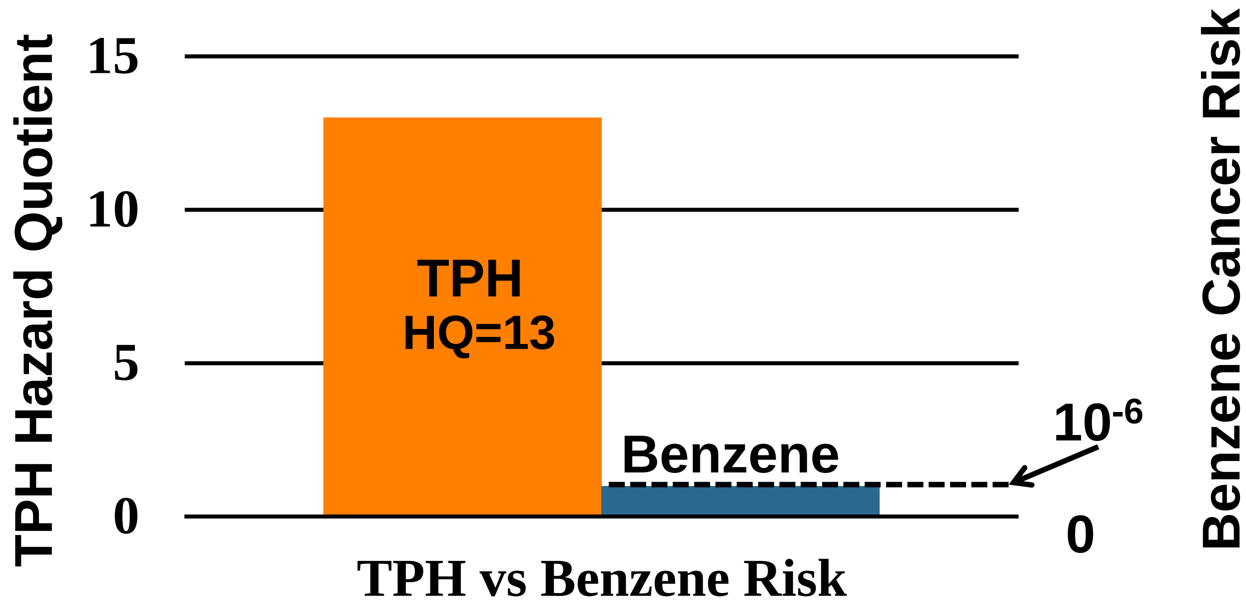
5ft Above Source
TPHg = 99,000,000 μg/m^3
Benzene = ND (<7,000 μg/m^3)
TPH:Benzene = >13,000:1

At Source:
TPHg = 310,000,000 μg/m^3
Benzene = 80,000 μg/m^3
TPH:Benzene = 4,000:1

TPH predicted to still be 4X to 13X above PVI action level when benzene PVI action level met.

Site D PVI Risk Driver (JP-4)

Critical TPH:Benzene Ratio = 710:1
Average Measured TPH:Benzene Ratio = 9,100:1

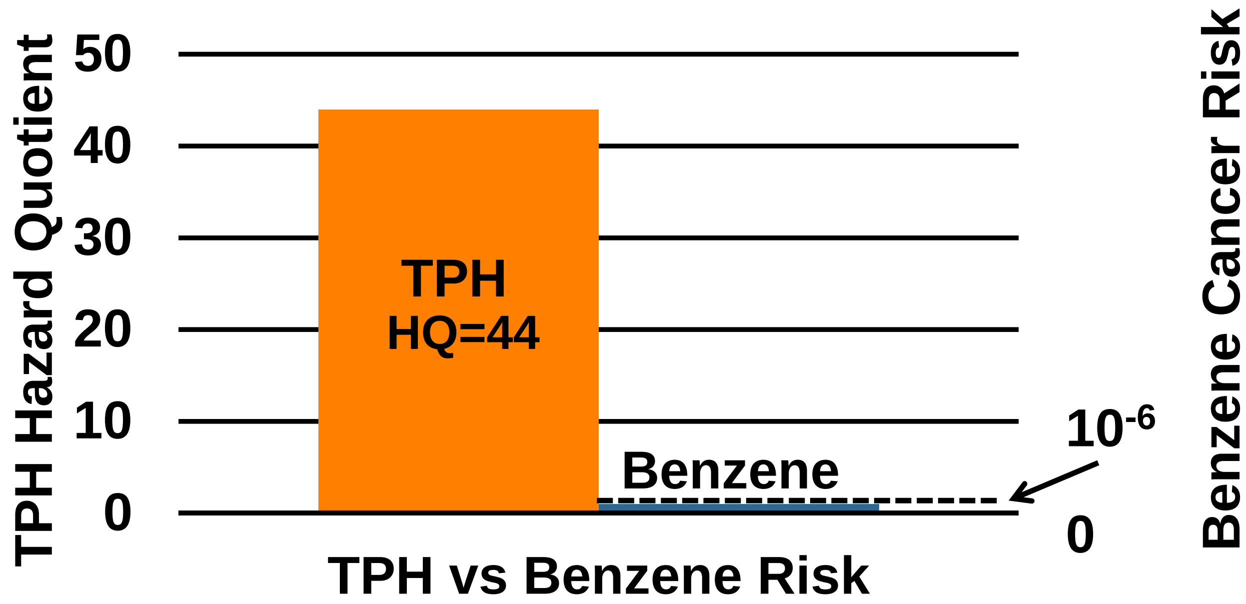


Based on TO-15 Summa Data

TPH *always* drives potential vapor intrusion hazards.
(TPH noncancer HQ>1 even when benzene risk = 10^{-6})

Site E PVI Risk Driver (Diesel)

Critical TPH:Benzene Ratio = 410:1
Average Measured TPH:Benzene Ratio = 54,000:1



Based on TO-15 Summa Data

TPH *always* drives potential vapor intrusion hazards.
(TPH noncancer HQ>1 even when benzene risk = 10^{-6})

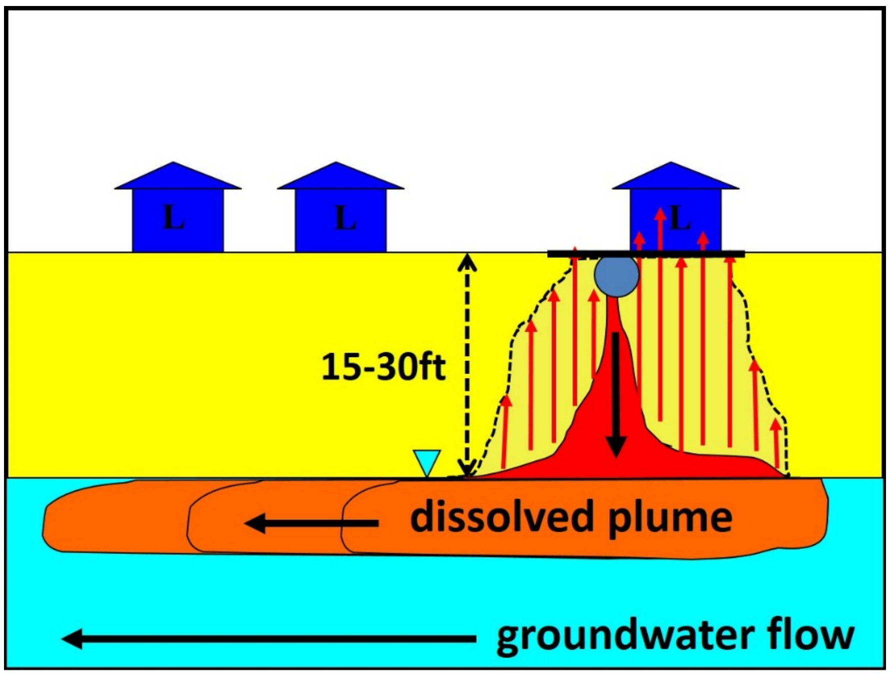
TPH vs Benzene as Vapor Intrusion Risk

Site/Fuel Type	Vapor Intrusion Risk Driver	
	TPH Drives Risk	*Benzene Drives Risk
USEPA PVI Database (mostly gasoline)	X	**X**
Site A (mostly AVGAS)	X	X
Site D (mostly JP-4)	X	
Site E (mostly diesel)	X	

***Assuming a target, 10^{-6} cancer risk is used for benzene.**

Fallacy #4: TPH Vapors Quickly Gone

4. TPH in vapors will not migrate >2-3ft from source above potential levels of concern for PVI (vs 15ft for benzene).



Hypothesis:

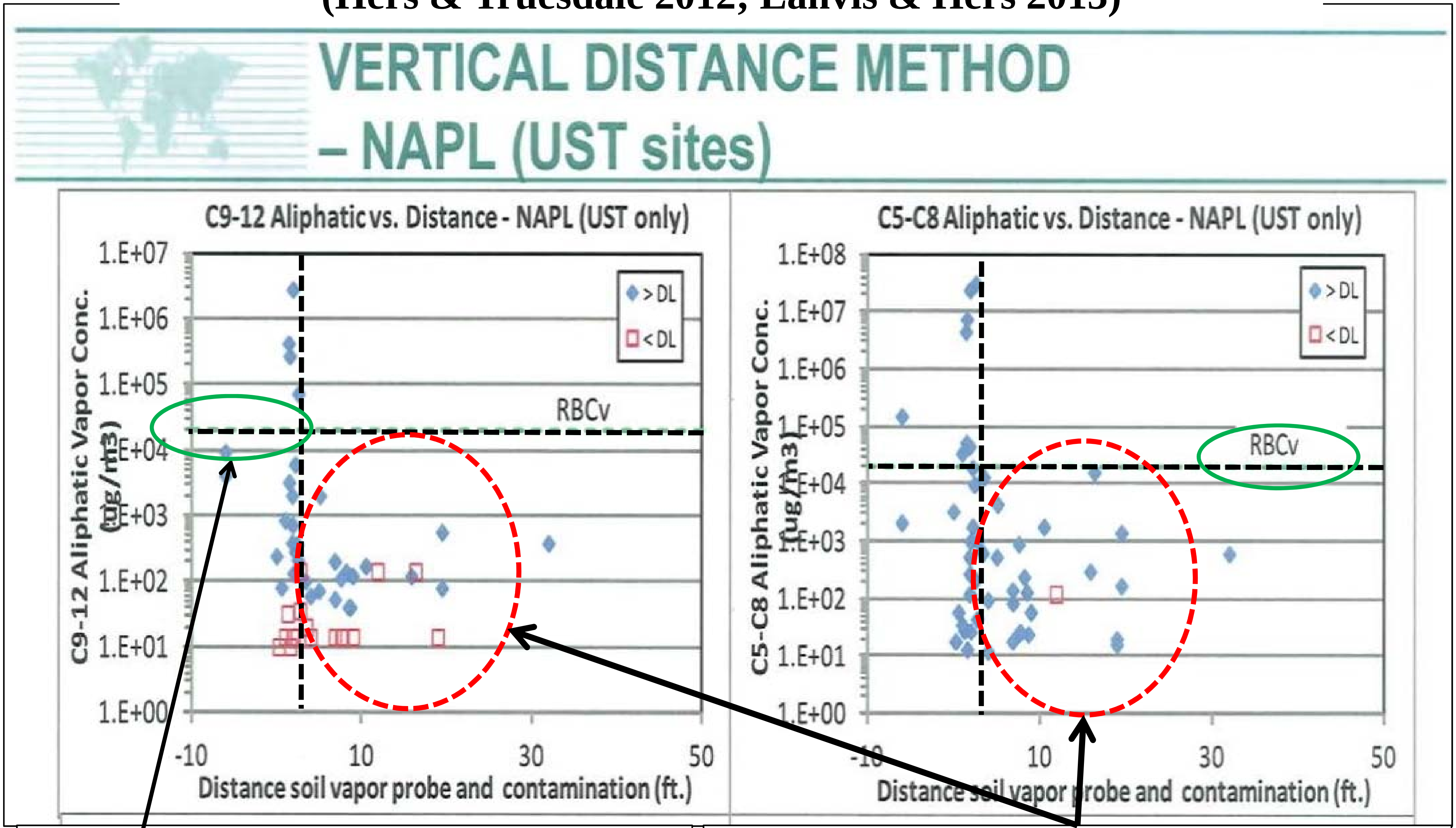
- Aliphatics more quickly removed from vapor plume by degradation;
- Aromatics (e.g., benzene) ultimately drive risk away from source;
- Easily testable in the field.

TPH Vertical Separation Distance

- **Assumes *TPH subslab PVI screening level* = 20,000 µg/m^3 (Not included in ITRC or USEPA PVI documents)**
- **2-3ft vertical separation distance proposed in early drafts of ITRC PVI guidance and referenced publications;**
  - **Based on very *limited field data*;**
  - **Models that assume a *higher, relative degradation rate for aliphatic* vs aromatic compounds in vapor plumes;**
  - **Predicts *relative enrichment* of vapors in BTEX away from source (i.e., TPH:Benzene ratio *decreases* as aliphatics are more rapidly removed);**
  - **2-3ft vertical separation distance not supported buy field data;**
  - **BTEX enriched vapor plumes *not observed* in field data (*opposite* suggested in Brewer et al 2013 but also limited data).**

Field Data vs TPH Vertical Separation Distance

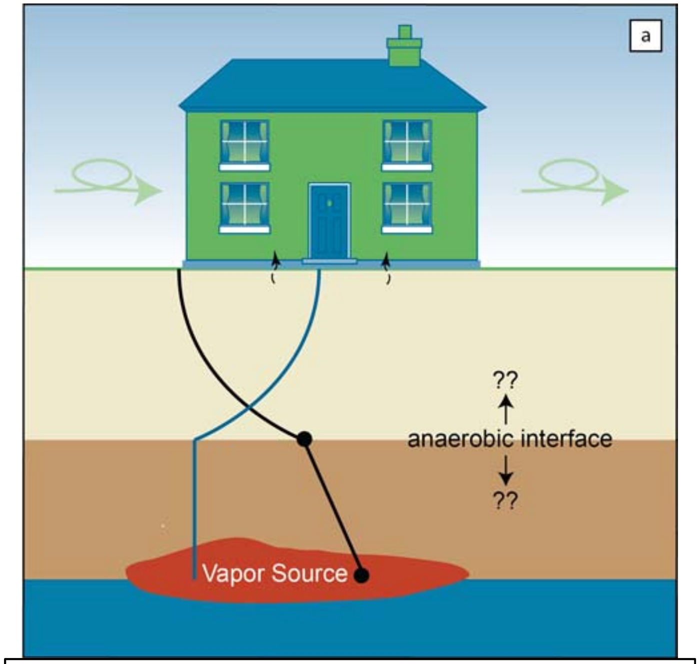
(Hers & Truesdale 2012; Lahvis & Hers 2013)



- TPH PVI screening level = 20,000 µg/m^3 (HDOH = 130,000 µg/m^3)
- Not discussed in ITRC PVI guidance.

- Very little data >3ft from source,
- Corresponding BTEX data not presented;
- Not reliable for generic separation distances

Model-Based Separation Distances (e.g., Biovapor)
(refer ITRC PVI webinar training)



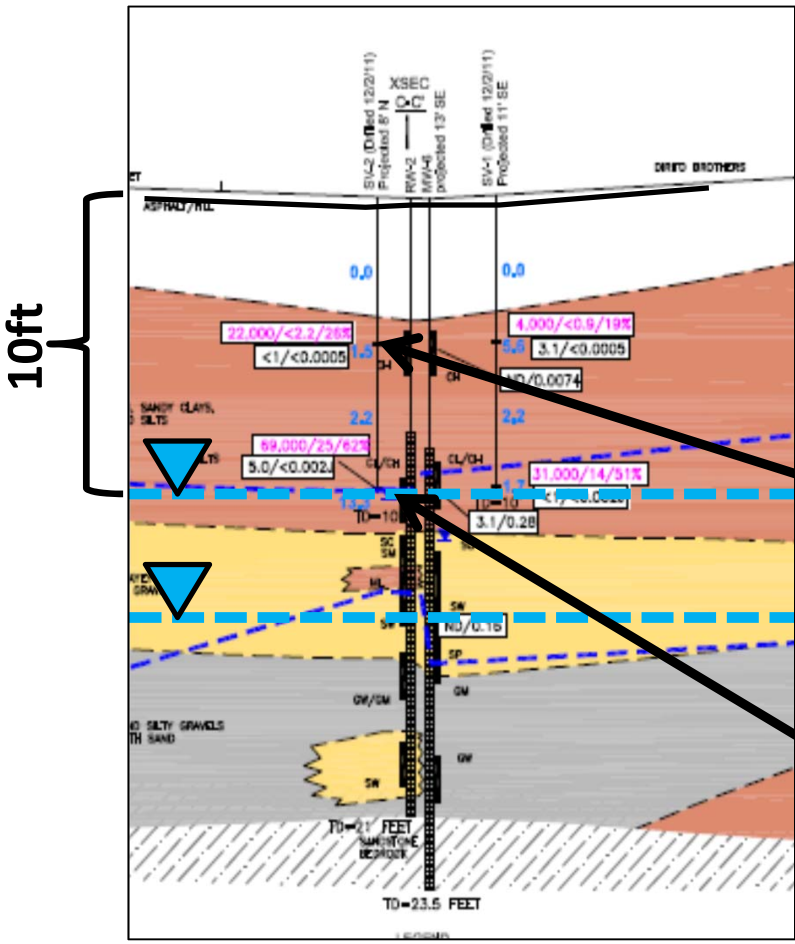
(from ITRC 2015 PVI webinar)

Vapor Intrusion Models

- **Models are great learning tool;**
- **Use to assist development of remedial actions and long-term management plans;**
- **"Models tell you exactly what you tell them to tell you."**
- **Significant variability within and between sites;**
- **Model results can be highly inaccurate;**
- **<u>Always</u> confirm F&T PVI models with field data.**

TPH Soil Vapor Field Data

- HODH field study: TPH significantly >130,000 µg/m^3 five- to ten-plus feet from source (free product present);
- Similar observations at other sites in Hawai'i and from mainland;
- Default TPH vertical separation distance of 2-3ft isn't protective;
- 15-30ft separation distance appears adequate for most sites.



Example California Gasoline Site (Part 2)

- TPHg significantly above 20,000 µg/m^3 5ft from source;
- Apparent relative *enrichment* of TPH with respect to benzene with distance.

5ft Above Source

TPHg = 99,000,000 µg/m^3

Benzene = ND (<7,000 µg/m^3)

TPH:Benzene = >13,000:1

At Source:

TPHg = 310,000,000 µg/m^3

Benzene = 80,000 µg/m^3

TPH:Benzene = 4,000:1

Where's the Benzene?

- **Preferential biodegradation of aromatics relative to aliphatics (inconsistent with laboratory studies)**
- **Preferential removal of aromatics from vapors due to partitioning into soil moisture (higher solubility);**
- **Original release of low-benzene gasoline;**
- **Most likely latter based on lack of consistent trend of relative *aliphatic:aromatic enrichment* in vapors away from source areas (limited data reviewed).**

Benzene Vertical Separation Distance Applies to TPH for Screening Purposes

ITRC PVI Guidance: Appendix F (F.12):
"Based on reviews of the PVI database, maximum vertical screening distances derived for other individual, indicator compounds (e.g., benzene) are also considered to be adequate for noncompound-specific TPH fractions."

PVI Summary and Implications

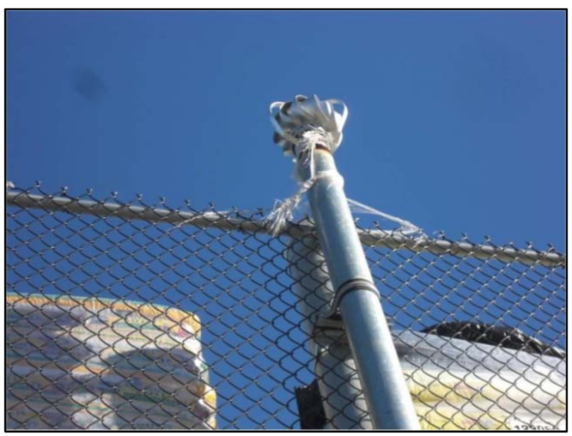
- ***Natural degradation*** **significantly reduces vapor intrusion risks from petroleum in comparison to chlorinated solvents;**
- ***Shallow (<15ft) petroleum free product*** **in soil or on groundwater can pose potential PVI risks;**
- **Vapor plumes from** ***jet fuels and diesel*** **are lower concentration than for gasoline, but can still pose potential PVI concerns;**
- **Petroleum vapors are dominated by** ***TPH aliphatics*****;**
- **Risk-based** ***indoor air and soil gas action (screening) levels*** **can be developed for TPH (site-specific or generic);**
- ***Benzene usually drives PVI*** **risk for older releases of gasoline (high benzene);**
- ***TPH usually drives PVI risk*** **for middle distillates and newer low-benzene gasoline releases;**
- ***Small pockets of residual contamination*** **do not pose a long-term, PVI risk regardless of concentration (limited mass);**
- **PVI concerns can typically be addressed by** ***removal of gross*** **contamination.**

Questions (use Zoom comment box)?

PVI Remediation: Former Gasoline Tank Farm (Honolulu)

Treatment of Grossly Contaminated Soil

Liquid Boot membrane.



Passive subslab venting.

Final Lowe's Store