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NIH National Institute of Environmental Health Sciences
GuLF STUDY
University of Minnesota Driven to Discover℠

The NIEHS GuLF STUDY: Estimation of workers' exposures through the inhalation route on four rig vessels near the well-site during the Deepwater Horizon oil spill

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Deepwater Horizon Explosion, April 20, 2010

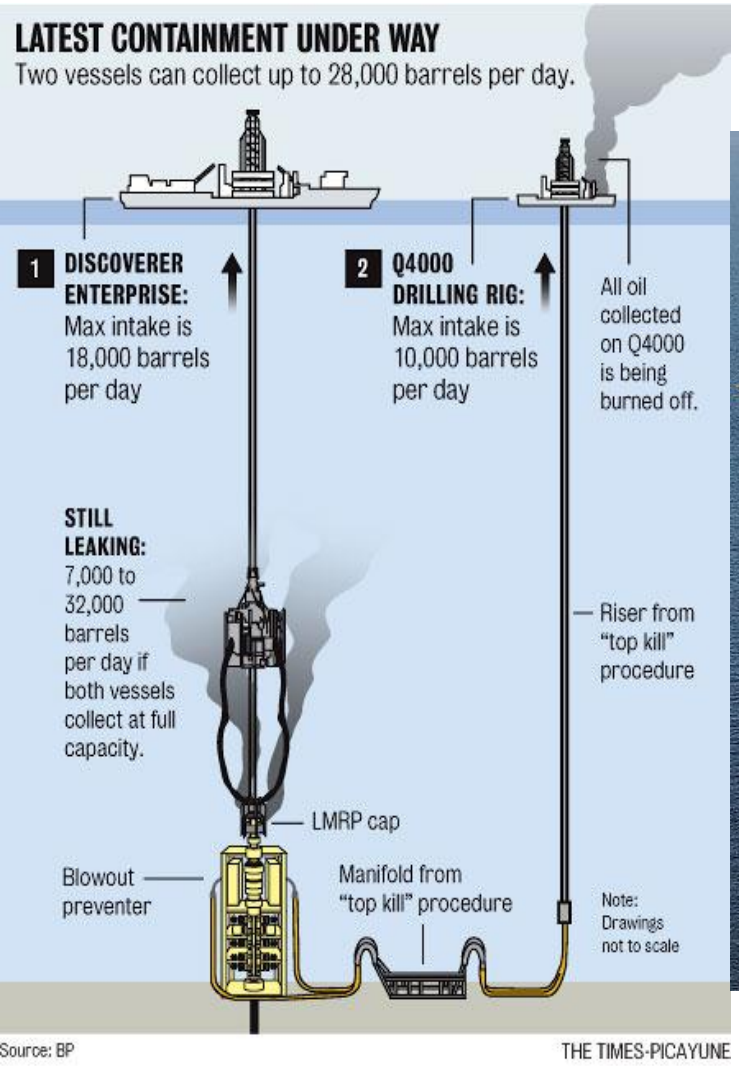
- Explosion killed 11 workers, injured 17; 98 others survived
- ~48 miles southeast of Louisiana coast
- The National Institute of Environmental Health Sciences (NIEHS) is conducting an epidemiological study (GuLF STUDY) to assess potential adverse health effects of ~33,000 workers involved in the fire, subsequent oil release, response, well capping and clean-up efforts.

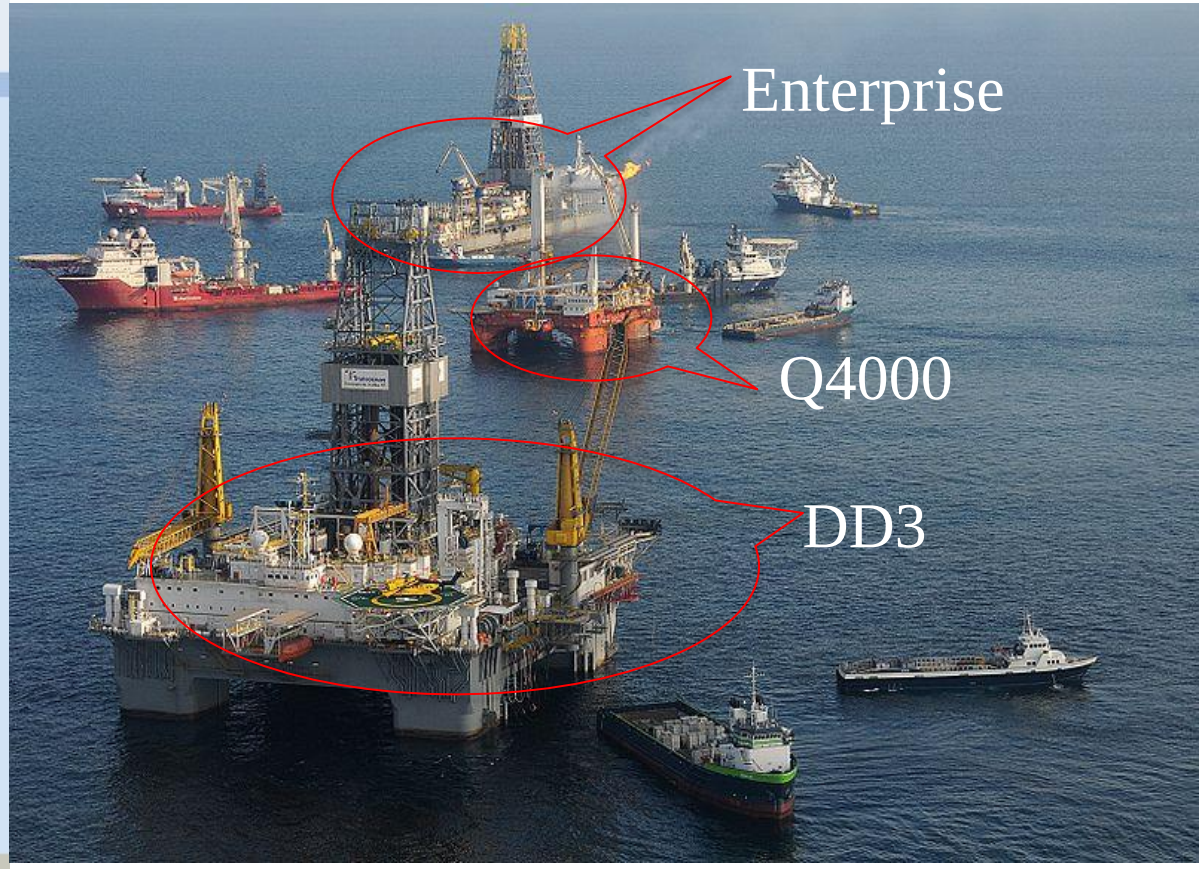
Objectives

- To characterize inhalation exposures on four rig vessels (DD2, Enterprise, DD3, and Q4000) for various exposure groups (EGs).
- Components of fresh and weathered oil including:
  - Benzene, toluene, ethylbenzene, xylene (BTEX chemicals)
  - Total hydrocarbons (THC, a composite of BTEX, hexane and other volatiles on the four rig ships).
  - 2-butoxyethanol (a major component of dispersants).

Enterprise, DD3, DD2, and Q4000

- **Enterprise:** Collected oil and gas, flared gas and mitigated leak
- **DD3:** Drilled primary relief well beginning May2, 2010
- **DD2:** Drilled backup relief well beginning May 16, 2010
- **Q4000:** Flared oil and supported leak mitigation


LATEST CONTAINMENT UNDER WAY
Two vessels can collect up to 28,000 barrels per day.
1 DISCOVERER ENTERPRISE: Max intake is 18,000 barrels per day
2 Q4000 DRILLING RIG: Max intake is 10,000 barrels per day
All oil collected on Q4000 is being burned off.
STILL LEAKING: 7,000 to 32,000 barrels per day if both vessels collect at full capacity.
Riser from "top kill" procedure
LMRP cap
Blowout preventer
Manifold from "top kill" procedure
Note: Drawings not to scale
Source: BP
THE TIMES-PICAYUNE


Enterprise
Q4000
DD3

Methods

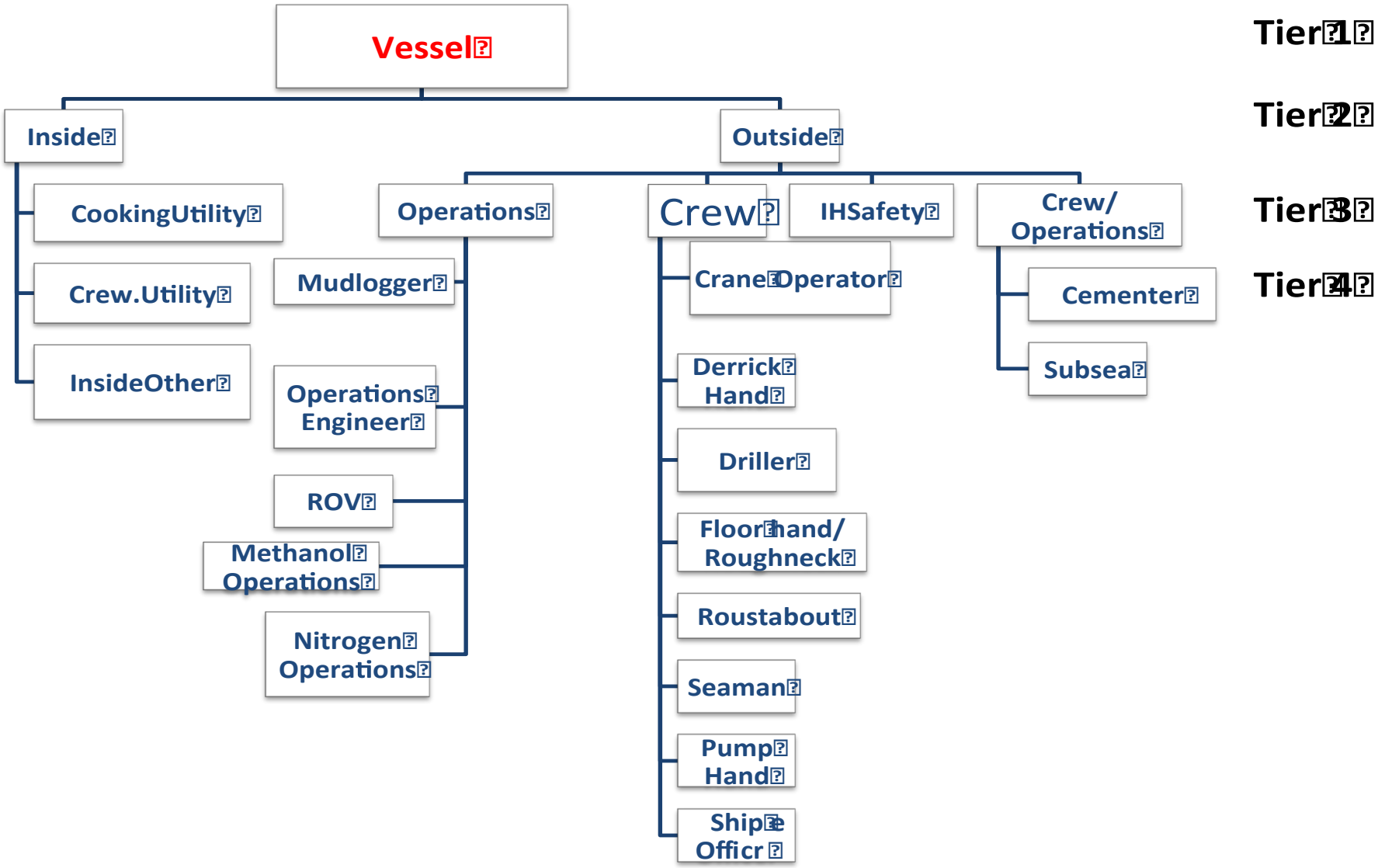
Development of job exposure matrix:

•~65 EGs standardized across the four vessels based on: Job titles, Tasks and activities, and time period.

•The spill response and clean-up effort was divided into four zones: hot zone (a five mile radius around the well head) , offshore other than hot zone, near shore (three miles from shore), and on-land. The hot zone was a restricted area where the four rig vessels were stationed to repair the main well, collect oil and gas, and drill the relief wells.

•The hierarchy has four tiers, with Tier 1 being the most general and Tier 4 the most specific.

Hierarchy of EGs on the Enterprise



Dividing exposure into time periods

- The cleanup period, which lasted from April – Dec, 2010, is divided into 4 time periods (TP):
  - TP 1a: April 20 to May 14, 2010
    - Crude oil leaking from well and prior to the injection of dispersant at the well head
  - TP1b - May 15 - July 15, 2010
    - Crude oil leaking from well and dispersant being injected at the well head. The well head successfully capped on July 15, 2010 and the release of oil ended.
  - TP 2: July 16 – Aug 10, 2010
    - The relief wells were completed in early August and bottom capping of the well was completed by August 10, 2010. Bottom capping relieved pressure on the original well casing
  - TP 3: Aug 11 – Dec 31, 2010
    - Ships were being decontaminated and refurbished for post response assignments

Methods

Significant number of measurements of THC and BTEX chemicals are censored (< LOD) for all four rig ships.

Vessel	N	% < LOD					N	%<LOD
		THC	Benzene	Toluene	Ethylbenzene	Xylene	Hexane	Hexane
DD2	339	34	96	58	61	50	200	75
Enterprise	436	11	87	36	58	41	274	22
DD3	449	30	95	24	37	34	287	45
Q4000	207	20	92	68	63	39	197	67

Significant correlation between THC and BTEX chemicals (Censored regression analysis).

$$\ln(\text{analyte}_i) = \beta_0 + \beta_1 * \ln(\text{THC}_i) + \varepsilon_i$$

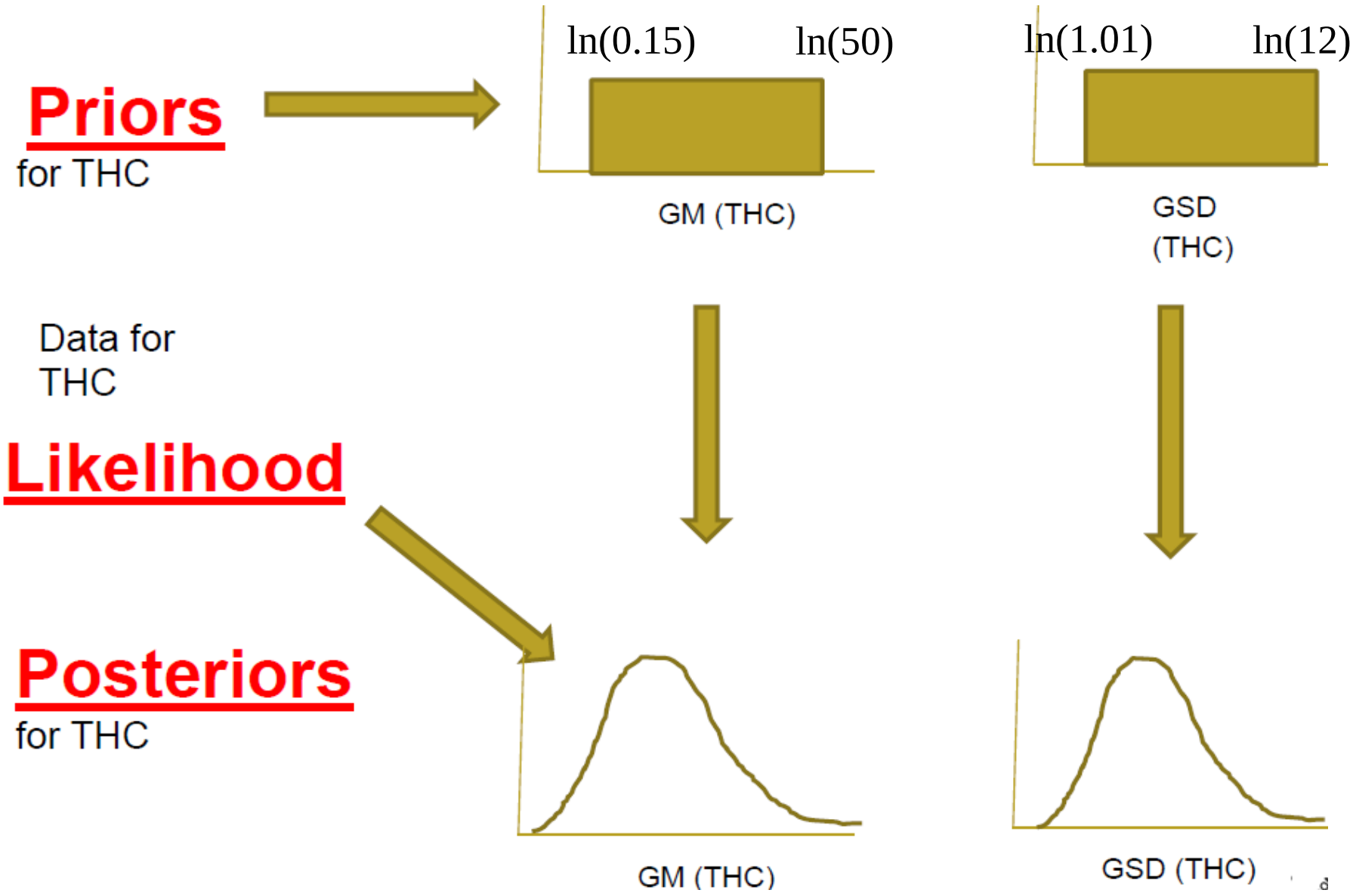
Time		N	Analyte Percent Censored	THC Percent Censored	Median	2.5 Quantile	97.5 Quantile
Time Period 1A	Intercept*	22	68.2	4.6	-17	-27.56	-11.36
	Slope*				2.51	1.83	3.73
Time Period 1B	Intercept*	345	37.1	7.5	-5.5	-5.97	-4.99
	Slope*				1.15	1.09	1.21
Time Period 2	Intercept	31	16.1	3.2	-2.35	-5.15	0.47
	Slope*				0.75	0.28	1.21
Time Period 3	Intercept*	24	95.8	75.0	-21.09	-36.96	-5.18
	Slope*				3.42	0.92	5.82

Slopes and intercepts between **THC and xylene** for the Outside group on the Enterprise. (* = statistically significantly different from zero).

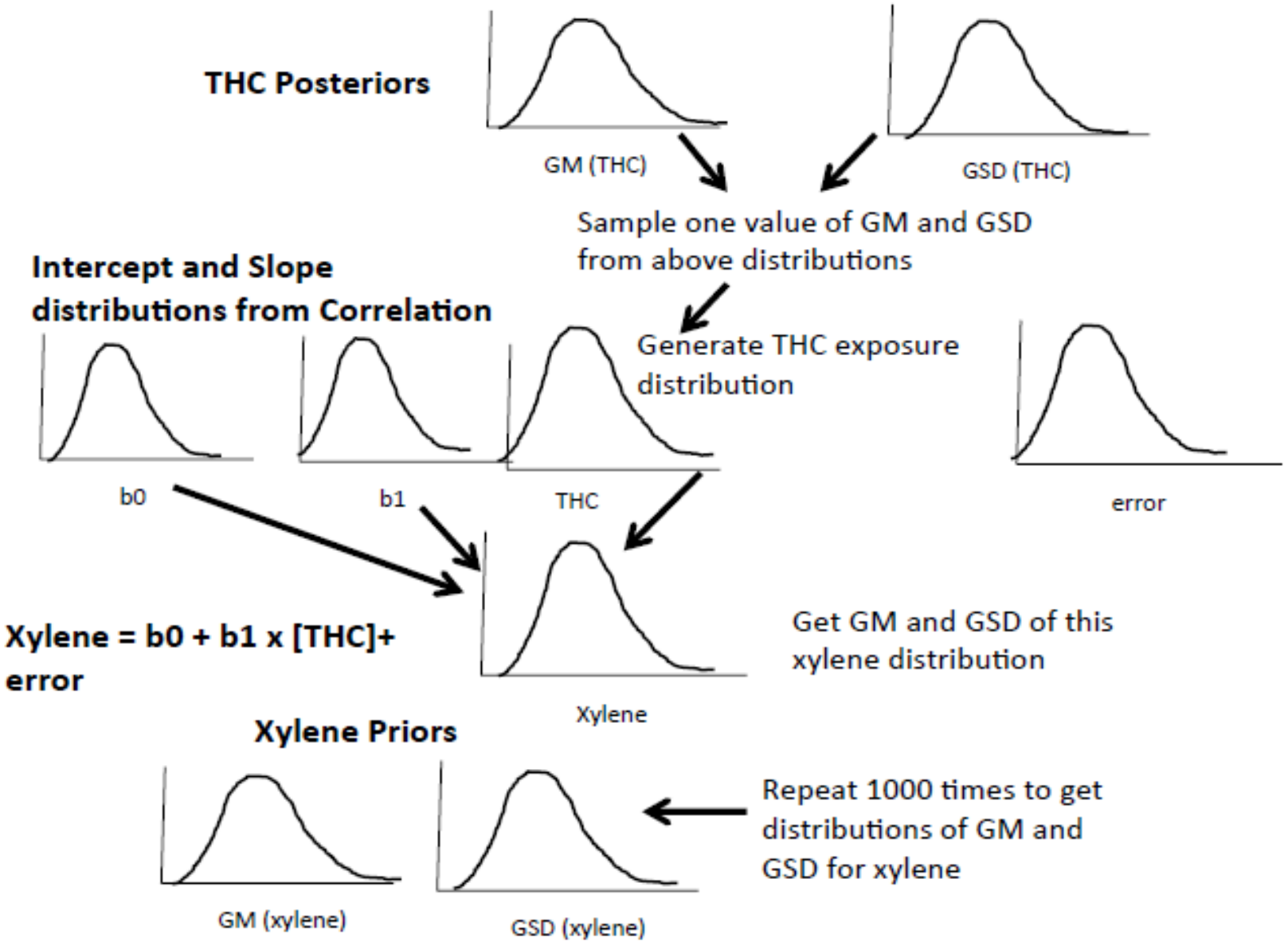
Bayesian Methods

- Methods developed to obtain estimates for the
  - Arithmetic mean (AM)
  - 95^{th} percentile
  - Geometric mean
  - Geometric standard deviation

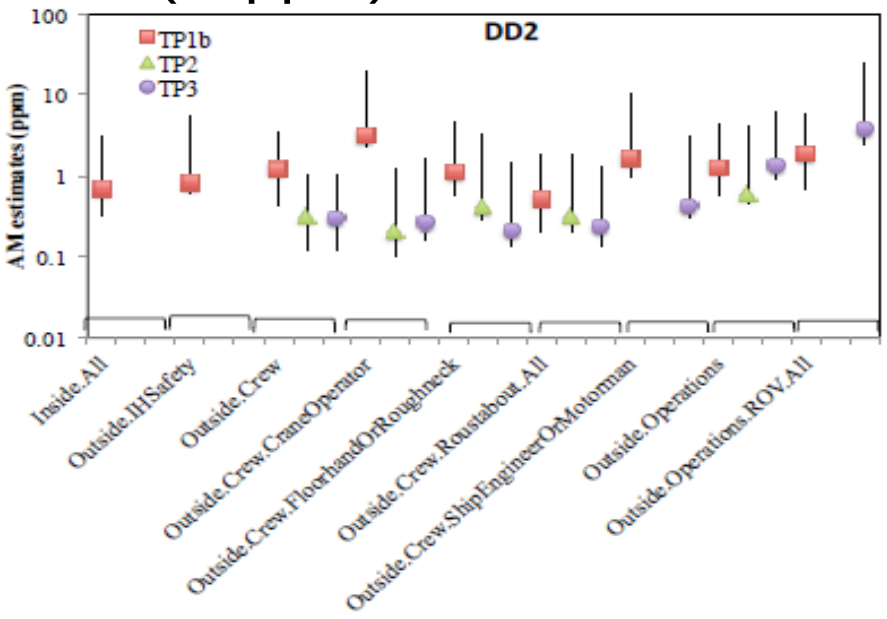
Development of THC posterior distributions using prior distributions and likelihood functions using measurement data.

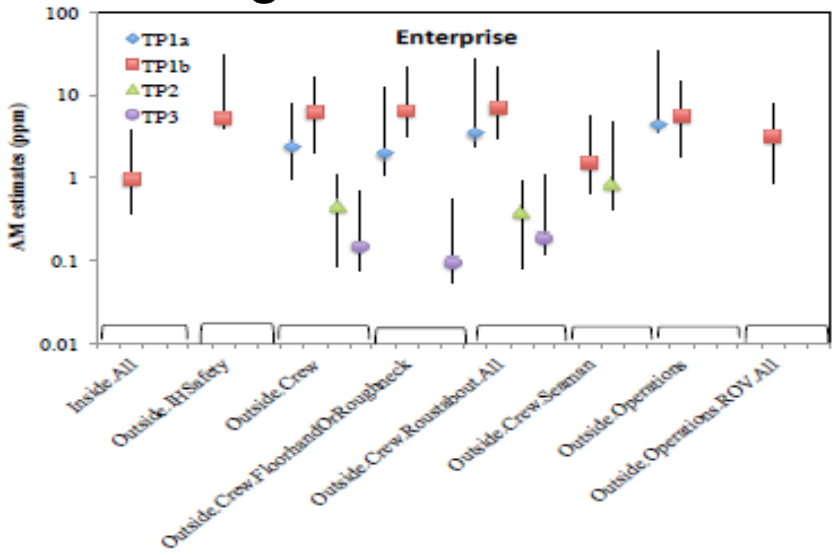


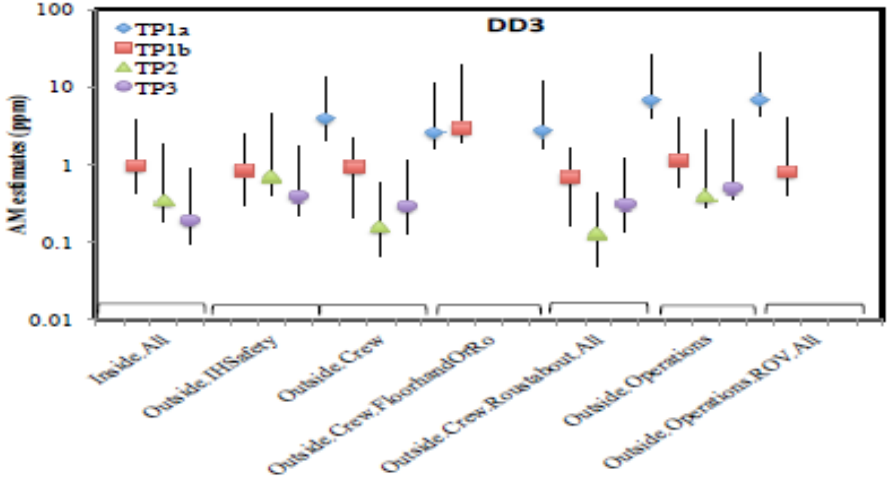
Strategy for developing priors for each EGs for the analysis of BTEX chemicals (xylene is used as an example).

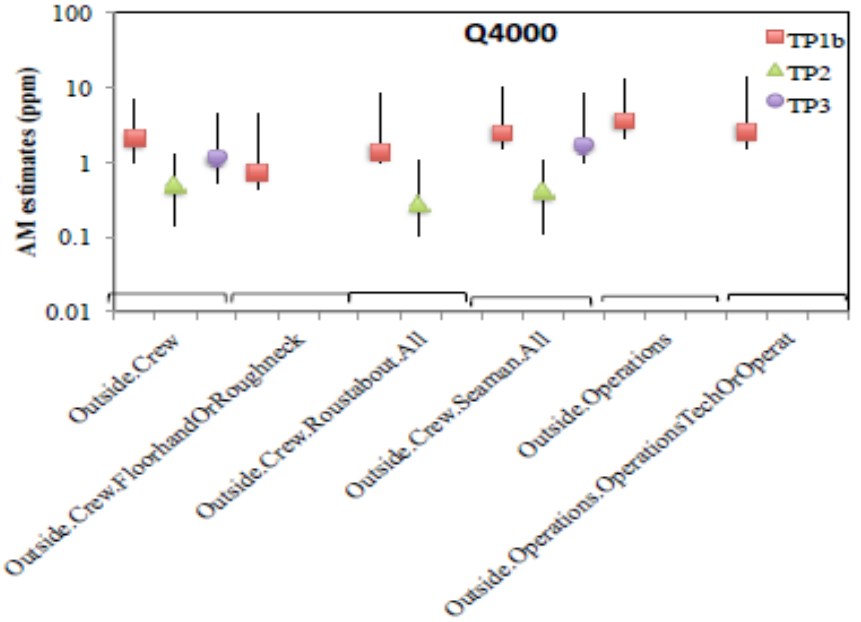


Estimates of the AM and 95% CI for **THC exposures** (in ppm) for selected EGs on the four rig vessels

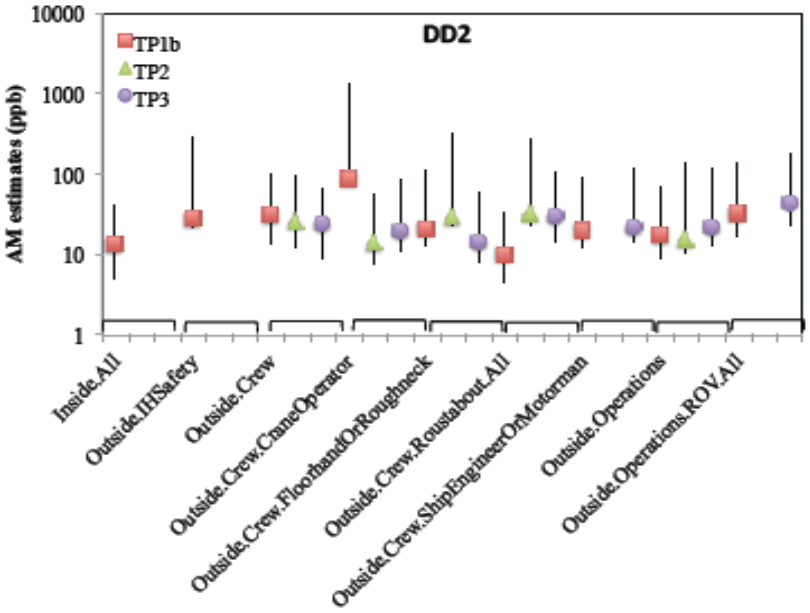


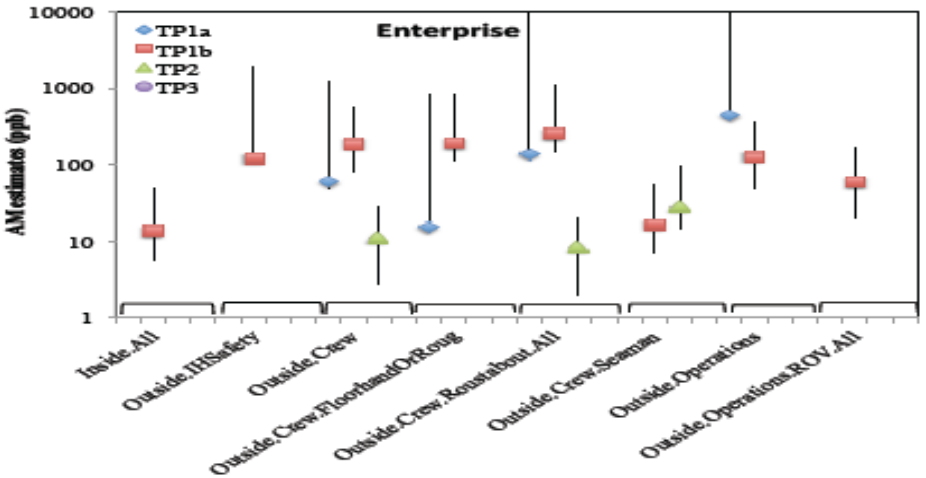


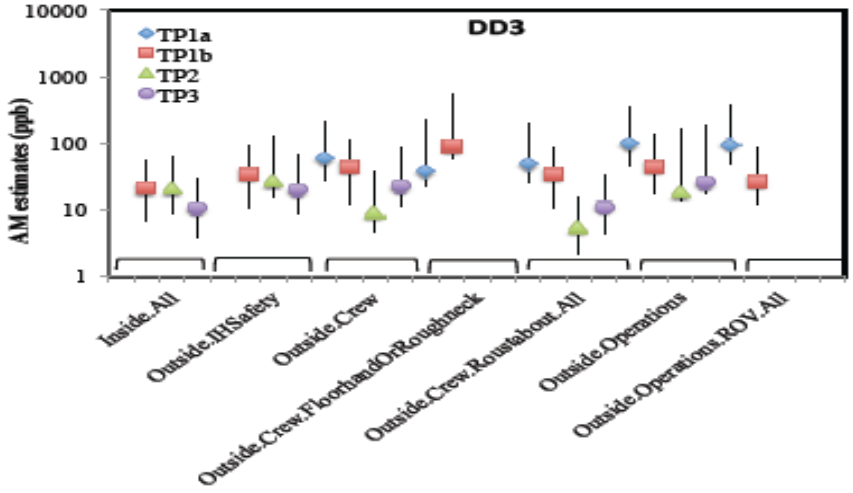


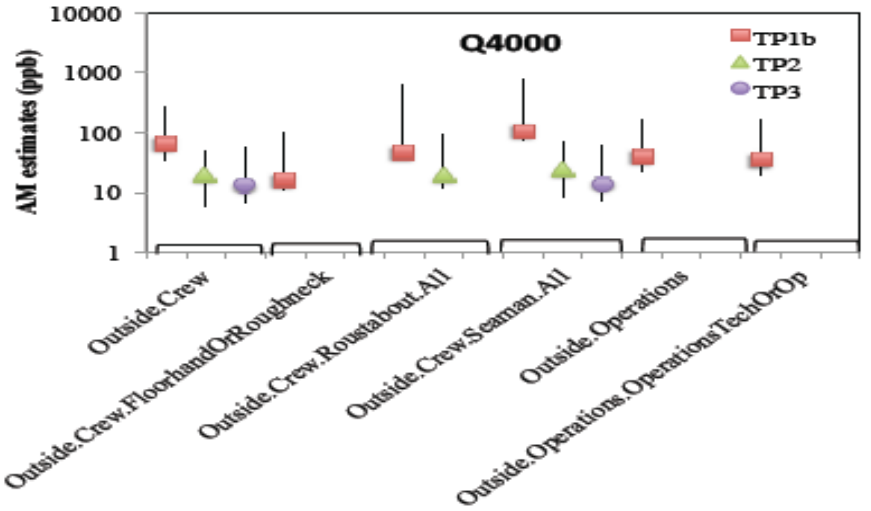


Estimates of the AM and 95% CI for **Xylene exposures** (in ppb) for selected EGs on the four rig vessels









Conclusions

- We used a Bayesian method that can analyze data with detection limits to develop estimates of occupational exposures to THC, BTEX chemicals, and hexane on the four rig vessels in the hot zone.
- THC measurements were least censored compared to other chemicals evaluated. THC exposure trends over time varied by time period, ships, and EGs.
- Generally highest exposures were observed in TP1b when the oil was continuously leaking until the pipe was successfully capped. Exposures gradually decreased over time in selected EGs except a few that might be involved in decontamination effort.
- The variability of the EGs were generally high, reflecting the non-routine, time-dependent nature of spill response efforts.