Screening Level Assessment of Risks Due to Dioxin Emissions from Burning Oil from the BP Deep Water Horizon Gulf of Mexico Spill

(slides prepared at ARL Jan 2011, based on earlier ARL materials prepared Oct 2010)

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As one of the methods to respond to the oil spill, 410 separate *in-situ* burns were carried out between April 28 and July 19, burning an estimated 222,000-313,000 barrels of oil (~5% of the total amount of leaked oil)

**Dioxin Risk?**

- Polychlorinated dibenzo-p-dioxins and furans (referred to as PCDD/F or “dioxin”) are formed in trace amounts during combustion
- The presence of chlorine in the combustion environment can enhance PCDD/F formation
- The marine environment has relatively high levels of chlorine, and so there was concern that the oil burning activities might be releasing harmful levels of dioxin
- There are 209 different PCDD/F congeners; 2,3,7,8-TCDD is the most toxic and is one of the most potent carcinogenic compounds ever discovered
A joint “screening level” project was undertaken by the EPA and NOAA to assess the potential dioxin risk from the oil burning activities

Overall Outline of Project

- Overall goal was to estimate inhalation risk to workers and residents, as well as risk from consumption of dioxin-contaminated seafood
- This was a screening level analysis -- if the risks appeared high enough, a more detailed assessment would be carried out
- Dioxin was measured in DWH-oil-burning plumes by EPA to estimate emissions factor
- Relevant burn-by-burn data and meteorological data were assembled for use as model inputs
- Atmospheric dispersion models used to estimate air concentrations of dioxin downwind of the burns; inhalation exposure and cancer risks from this exposure were based on these estimates.
- Atmospheric deposition was estimated by dispersion models and utilized in a food chain model to estimate dioxin concentrations in fish; cancer risk from fish consumption based on these estimates.

NOAA ARL’s Contributions

- Carrying out analysis on burn-by-burn data to create a dataset suitable for model input. (ARL appreciates the assistance of NOS/OR&R in relaying these data.)
- Assembling/archiving gridded meteorological data for use in ARL’s atmospheric modeling; extracting data from these archives to support EPA’s near-field modeling work
- NOAA ARL was asked by U.S. EPA to begin modeling atmospheric fate and transport of emitted dioxin on June 18, 2010 to inform assessment of risks to the general population. Numerous model runs were carried out over the next four months as additional data became available.
- This ARL atmospheric modeling analyzed the regional fate and transport of emitted dioxin, on a congener-specific and burn-by-burn basis, using a specially configured version of the HYSPLIT (Hybrid Single Particle Lagrangian Integrated Trajectory) model designed to simulate atmospheric PCDD/F.
- Based on this modeling, ARL provided screening-level values of atmospheric deposition and on-shore concentrations for use in the EPA’s risk assessment.
EPA measured the dioxin emissions from several plumes to estimate an emissions factor for the oil-burning activities


**Schematic illustration of the in situ burn operations and plume sampling.** (Figure 1 from Aurell and Gullett, 2010)
The NOAA HYSPLIT model was used to simulate the atmospheric fate and transport of dioxin emitted from the burning activities

- Each of the 410 surface burn events modeled.
- Simulation from 4/28/2010 (date of first burn) to 7/22/2010 (3 days past last burn 7/19/2010).
- Hourly met data from NOAA NCEP NAM weather model.
- Met data horizontal resolution: 12 km.
- Met data vertical resolution: 18 of 39 levels <= 1500m.
- Overall model domain was 10° x 10° centered at spill.
- Results tabulated on 5° x 5° grid; resolution of 10 km.
- Time series data tabulated at 14 illustrative sites.
- Burn-specific buoyancy-driven plume rise estimated.
- Simulated each 2,3,7,8-substituted PCDD/F congener.
- Individual congener simulations added together using the congener-specific emissions factors and congener-specific toxic-equivalence factors, to create results as TEQ.

Modeling results tabulated at 10km resolution on a 5° x 5° grid and at 14 illustrative sites

Simulation results grid and locations of 14 illustrative sites chosen for more detailed accounting
Ground-Level Atmospheric Concentrations

**Ground-level dioxin concentrations were very episodic, due to the fact that burns occurred sporadically and the weather was highly variable.**

Average modeled ground-level PCDD/F concentrations (fg TEQ/m3) over the entire modeling period April 28 – July 22, 2010.

Illustrative locations shown, numbered in descending order from highest to lowest average concentration (fg TEQ/m3):

1 – S.E. Plaquemines (0.019)  
2 – Dauphin Island (0.016)  
3 – Pensacola (0.012)  
4 – Venice (0.0072)  
5 – Stake Island (0.0069)  
6 – Pascagoula (0.0011)  
7 – Grand Isle (0.0010)  
8 – Gulfport (0.00095)  
9 – Biloxi (0.00066)  
10 – Grand Bay NERR (0.00065)  
11 – Mobile (0.00052)  
12 – Slidell (0.00025)  
13 – Houma (0.00018)  
14 – New Orleans (0.00008)

Time series of modeled hourly average PCDD/F concentrations (at 10 meter elevation) for a portion of the burning period (June 8-24) at several illustrative locations in the Gulf of Mexico region resulting from estimated dioxin emissions from reported burn events.

These data were used by EPA used to estimate on-shore inhalation exposure and the cancer risk associated with that exposure.
Due to plume rise, the highest average deposition flux occurred approximately 50-75 km away from the DWH spill site.

EPA used these data as input to a food chain model to estimate dioxin concentrations in fish and risks to the general population from eating those fish.

~25% of the emitted PCDD/F was deposited within 250 km of the DWH site.

Total PCDD/F deposition flux (fg TEQ/m2) over the entire modeling period April 28 – July 22, 2010.
Inhalation exposure of on-shore residents

Fish-consumption exposure of on-shore residents

Inhalation exposure of workers in the immediate vicinity of the burns

The red bars shown are typical screening “threshold” values for cancer risk assessments

Current Status

- Manuscript underwent internal (EPA and NOAA) and external peer reviews
- Manuscript published: Screening Level Assessment of Risks Due to Dioxin Emissions from Burning Oil from the BP Deepwater Horizon Gulf of Mexico Spill, *Environmental Science and Technology* 2010, 44, 9383–9389

Issues

- This risk assessment was for dioxin emissions only. It did not consider other chemicals likely emitted, e.g., PAH’s (polycyclic aromatic hydrocarbons).
- This risk assessment only considered emissions from in-situ oil burning. It did not consider emissions from other DWH-related oil-burning activities, e.g., on the Q-4000.
- There were significant uncertainties in available information about the characteristics (e.g., area of burn, plume rise) of individual burn events. For future incidents, additional information (e.g., photo’s of plumes) would improve accuracy of risk assessments
Publication Detailing Study Results

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Abstract: The US Coast Guard has conducted intermediate studies in the construction of approximately 300,000 barrels of oil, with approximately 80,000 barrels of oil, in containers that are in the vicinity of the burned marine area. The study was designed to evaluate the effectiveness of oil burning as a countermeasure for reducing the risk of oil spills. The primary objectives of the study were to evaluate the impact of burning oil on the environment and to determine the effectiveness of the burning process in reducing the risk of oil spills.

Discussion:

The study was conducted in collaboration with the US Coast Guard and the US Environmental Protection Agency. The study was designed to evaluate the effectiveness of oil burning as a countermeasure for reducing the risk of oil spills. The primary objectives of the study were to evaluate the impact of burning oil on the environment and to determine the effectiveness of the burning process in reducing the risk of oil spills.

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Aerostat Sampling of PCDD/PCDF Emissions from the Gulf Oil Spill In Situ Burns

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Emissions from the site burning of oil in the Gulf of Mexico after the catastrophic failure of the Deepwater Horizon drilling platform were sampled for polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans (PCDD/PCDF) by a battery-powered instrument package that was remote from the surface fires. Aerosol sampling of PCDD/PCDF from the Gulf in situ burns has been made from oil fires and one only 0.25 km away from the surface fire of one of the oil spills. Similar conditions were reached during experimental, test-cased burns where similar burn patterns were compared with actual open-air spills. In both of these cases, the PCDD/PCDF sampling was done at sea level, approximately outside the smoke plume, and so the results remain valid for both the laboratory and in field conditions. To measure the potential emissions of PCDD/PCDF from the Gulf oil spills in situ, an aerosol-instrumented package was used to sample the plume emissions to determine PCDD/PCDF concentrations and an emission factor.

**Materials and Methods**

**Aerostat Operations at Sea.** A 4-10 m diameter, helium-filled aerostat, designed and built by Aerostar (Kingston, NY), was used to collect the aerosol (i.e., the “air”) on the oil along the entire flight path for sample collection. The aerostat was launched from the deck of the M/V Atlantis (Alvis Corporation), a 47 m long platform workboat. The aerostat was used to sample a cloud of aerosol-dissolved oil. The aerosol was observed above the clouds, which had a diameter of 6 km between 9 and 11 km, and the samples were collected at a height of 15 m above the cloud bottom. The samples were collected on a 5 m radius from the aerostat and wereDev. Environ. Sci. Technol. 2010, 4, 9431–9437

**Designing Science in a Crisis: The Deepwater Horizon Oil Spill**

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*In a crisis, there is little room for protracted debate or negotiation. Decisions can spill tremendous consequences and time is of the essence. The Deepwater Horizon (DWH) oil spill, like many disasters before it, challenged the scientific community to do their best work under dire circumstances. Scientists from more than a dozen federal agencies and the private and academic communities were called to the best science, expertise, and assets to bear on an unprecedented situation. As teams worked together to respond to what President Obama called “the worst environmental disaster America has ever faced,” scientists were denied the luxury of lengthy deliberation. In this issue of Environmental Science & Technology, two examples of “crisis science” designed and conducted by the U.S. Environmental Protection Agency (EPA) to support the DWH oil spill response are described. These represent the urgent situation they faced: one, EPA conducted comparative toxicity tests to determine the impact of dispersants. The other, EPA worked with other federal and state agencies and private partners to develop a new method to help predict the fate of oil spills.*


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additional information from the modeling analysis included in the Supplementary Information published along with the ES&T paper
Figure S-3. Average modeled concentrations at 10 meter elevation for the entire modeling period at 14 selected locations in the Gulf of Mexico region.

Note that the maximum values (representing emissions estimated assuming non-detected congeners were present at the detection limit) are the data tabulated in the caption to the map on slide #5 above.
Figure S-4. Maximum modeled one-hour average concentrations at 10 meter elevation for the entire modeling period at 14 selected locations in the Gulf of Mexico region.
• An earlier slide (#5 above) showed the average modeled ground level concentration over the entire modeling period April 28 – July 22, 2010 for each grid square.

• This figure shows the maximum 24-hour-average, modeled ground-level (10 m) concentrations for each grid square over the same period.

• The highest 24-hr-average modeled shoreline (or inland) concentrations was 0.92 fg TEQ/m$^3$, and this occurred at the grid square with centroid latitude/longitude of 30.2367 / -87.7872 (near the Bon Secour National Wildlife Refuge).

Figure S-5. Maximum modeled 24-hr average ground-level concentrations (fg TEQ/m$^3$) for each grid square over the entire modeling period April 28 – July 22, 2010.
• Grid cells were divided into categories based on the distance between their centroid and the spill site: 0-25 km, 25-50 km, 50-75 km, ... up to largest range of 225-250 km.

• This figure shows that the average modeled concentration [averaged over all directions] was largest in the distance range 100-125 km from the spill site.

Figure S-6. Average concentration as a function of distance range from the DWH spill site for grid squares, over the entire modeling period April 28 – July 22, 2010.
• This figure shows that the distance ranges with the highest single grid-square average concentrations are 125-150 km, 150-175 km, and 225-250 km.

• This figure just represents the values of the grid cell in a given distance range that has the highest average concentration over the modeling period.

• Note that the highest, modeled grid-cell overall average 10m concentration was 0.051 fg TEQ/m3, and this occurred at a grid cell approximately 125 km northeast from the spill site.

Figure S-7. Maximum grid-square average concentration as a function of distance range from the DWH spill site, over the entire modeling period April 28 – July 22, 2010.
Figure S-9. Total PCDD/F deposition flux (ug TEQ) in different distance ranges from the DWH spill site, over the entire modeling period April 28 – July 22, 2010.
This figure shows the same data as Figure S-9, above, except that the deposition totals have been normalized by the total estimated emissions from the oil burning activities (0.134 g TEQ).

It can be seen that approximately 4% of the total emissions were deposited in the range 50-75 km away from the spill site.

Approximately 26% of the emissions (on a TEQ basis) were deposited with 250 km of the spill site.

Figure S-10. Percent of total PCDD/F emissions from oil burning deposited in different distance ranges from the DWH spill site, over the entire modeling period April 28 – July 22, 2010.
• The HYSPLIT modeling was carried out over the domain shown in this figure.

• The domain extends approximately 5 degrees in each direction from the DWH spill site.

• A deposition mass balance analysis was performed for each of the seventeen 2,3,7,8-substituted congeners simulated with the HYSPLIT-SV model over this entire modeling domain, and the results are shown in the following slides.

• Note that all other modeling results presented here were tabulated and displayed on a smaller, finer grid, extending 2.5 degrees in each direction from the DWH spill site (shown in slide #4).

Figure S-11. Overall HYSPLIT-SV modeling domain on which the mass balance results of this section are based.
• This figure shows the fraction of total modeled deposition over the entire modeling domain accounted for by dry deposition, for both the vapor and the particle phases.

• For each congener, wet deposition accounted for the remaining fraction of total deposition.

• For example, for 2,3,7,8-TCDD, approx. 30% of the deposited mass was dry deposited in the vapor phase, about 2% was dry deposited in the particle phase, and the remaining 68% was wet deposited.

• The relative importance of different deposition pathways appears to be consistent with the expected vapor/particle partitioning behavior of the different congeners.

Figure S-12. Percent of total modeled deposition for a given congener over the modeling domain simulated to be dry deposited. For each congener, the remaining deposition was through wet deposition processes.
In this figure, the total deposition (on a TEQ basis) over the entire modeling domain is presented for each modeled congener.

Note that since the TEQ emissions factor for OCDD was zero, the modeled TEQ deposition for this congener is also zero.

It can be seen that the most important congeners contributing to deposition (on a TEQ basis) over the entire domain were 1,2,3,7,8-PeCDD and 2,3,4,7,8-PeCDF.

Wet deposition was the most important deposition pathway for each of these two congeners.

Figure S-13. Total deposition of each congener over the entire modeling domain, using the model inputs as described in the main paper, e.g., upper end of range of amount of oil burned and assuming congeners not detected during the emissions testing were present at their detection limit.
In this figure, the fraction of the total emissions deposited over the entire modeling domain is shown for each congener.

It can be seen that approximately 40% of the total emissions were deposited in the modeling domain for each congener.

Figure S-14. Fraction of the total emissions of each congener deposited over the entire modeling domain.