

## Case Study

# Deepwater Horizon Response Workers Exposure Assessment at the Source: MC252 Well No. 1

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### INTRODUCTION

The National Institute for Occupational Safety and Health (NIOSH) conducted a health hazard evaluation (HHE) of Deepwater Horizon Response workers in response to a request submitted by BP management on May 28, 2010. The NIOSH HHE addressed numerous potential worker exposures on land; at the land-water interface; and with a variety of vessels carrying out oil release response activities on, in, and beneath the waters of the Gulf of Mexico.<sup>(1)</sup> This case study reports the NIOSH worker exposure assessment completed for workers aboard two main vessels working to contain, control, and ultimately stop the release of oil into the Gulf of Mexico from the damaged blow out preventer (BOP) at the site of the Deepwater Horizon Mississippi Canyon (MC) 252 Well No. 1 oil release. This assessment was part of a series of requests from BP concerning workers involved in the response. NIOSH evaluated exposures of workers closest to the oil release, at the source, on June 21–23, 2010.

### BACKGROUND

MC252 Well No. 1 is located offshore approximately 50 miles southeast of Venice, Louisiana, at a depth of 5000 feet. The BOP had been connected to the riser of the Deepwater Horizon drilling rig prior to April 20, 2010. An explosion, fire, and sinking of the rig, that began on April 20, 2010, produced an unprecedented oil release into Gulf waters.

NIOSH investigators began conducting worker exposure assessments involving the oil release on June 4, 2010. Exposure characterization efforts prior to the NIOSH source evaluation involved work activities including dispersant applications; in situ oil burns; barge oil vacuuming operations; offshore oil recovery efforts; and equipment preparation, cleaning, and decontamination. Prior industrial hygiene sampling included long- and short-term sampling; integrated full-shift (personal breathing zone (PBZ) and area sampling), task-specific, grab, and direct reading sample collection; and the use of summa canisters and thermal desorption tubes. Summa canisters and thermal desorption tubes facilitated identification of potential airborne contaminants. Contaminants collectively evaluated by NIOSH at other locations, prior to this exposure assessment aboard two source control vessels located above the MC 252 Well No. 1 oil release, included aldehydes, aromatic and aliphatic compounds, 2-butoxyethanol, carbon monoxide, diesel exhaust, dipropylene glycol butyl ether, hydrogen sulfide, mercury, polynuclear aromatic hydrocarbons (PAHs), limonene, propylene glycol, and total hydrocarbons (THCs). Laboratory screening of bulk samples and bulk air samples, including the summa canisters and multisorbent

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thermal desorption (TD) tubes, preceded analyses of other sorbent media. This allowed for further definition of contaminants of potential interest that could be evaluated in subsequent analyses and exposure monitoring. These first survey results were used to develop the NIOSH worker exposure assessment aboard vessels at the source of the oil release.<sup>(2-5)</sup>

BP provided us with recent offshore air monitoring results from continuous contaminant monitoring obtained aboard the source control vessels. Airborne contaminants and atmospheric hazards monitored on the vessels by BP were volatile organic compounds (VOCs), lower explosive levels (calibrated for methane), percent oxygen, hydrogen sulfide (H<sub>2</sub>S), carbon monoxide (CO), benzene, sulfur dioxide (SO<sub>2</sub>), and particulate matter less than 10  $\mu$ m aerodynamic diameter (PM10).<sup>(6)</sup> These latter two contaminants were measured for source control vessels (Discoverer Enterprise [Enterprise] and Q4000) that were flaring gas or gas and oil as part of containment or production activities. The majority of environmental and personal exposure data collected on the Development Driller II (DD II) and Enterprise, that was provided to NIOSH investigators during the site visit, had been below the lowest of the stepped BP action levels triggering corrective measures. These lowest current action levels requiring specific actions for VOCs, benzene, CO, H<sub>2</sub>S, SO<sub>2</sub>, and PM10 were: 50 ppm, 0.5 ppm, 25 ppm, 5 ppm, 1 ppm, and 0.35 mg/m<sup>3</sup>, respectively.<sup>(7)</sup> Airborne concentration data collected by BP and made available to NIOSH before the source was visited indicated that the contaminants previously identified were generally low compared with occupational exposure limits (OELs).

Completing an exposure assessment survey at the source was of interest because it allowed NIOSH to assess response workers' potential for exposure at a point closest to the ongoing crude oil release. NIOSH investigators and others involved in the Deepwater Horizon response postulated that workers on the source control vessels had the greatest potential for exposure to contaminants from the oil. Their proximity into the source made them the most likely group to be exposed to the volatile crude oil constituents released into the atmosphere above the damaged well. In addition, conditions on the vessels providing enclosures or conduits for chemical vapors, such as the moon pool of the Enterprise, could provide opportunities for increased exposure. Flares on two source control vessels, one on the Enterprise and the other on the Q4000, created possible exposures to combustion byproducts. Potential for worker exposure to dispersants, however, was considered to be to be less likely than for other response workers.

The DD II is a semi-submersible drilling unit with an operating water depth of 7500 ft (2286 m) and a drilling depth of 37,500 ft (11430 m) (Figure 1). The DD II contains all equipment and materials for drilling operations, including cranes; drilling equipment; hoisting equipment; storage; drill mud conditioning (mixing, cleaning, recirculating), and well control equipment.<sup>(8)</sup> The DD II was not involved with oil collection from the damaged BOP, and at the time of the NIOSH evaluation was operating in drilling mode preparing



**FIGURE 1.** The Development Driller II from the Enterprise.

one of two relief wells. One hundred sixty-seven people were on board.

The Enterprise is a deepwater, double-hulled, dynamically positioned drillship (Figure 2). This vessel can perform a range of subsea operations, including laying ultra-deepwater pipelines and providing extended well testing and storage capabilities. In addition to containing all the equipment and materials found on drilling rigs, the Enterprise can collect and hold about 100,000 barrels of crude oil.<sup>(9)</sup> At the time of the NIOSH evaluation, the Enterprise was located above the damaged BOP operating in a recovery and production mode. It was collecting about 25,000 barrels of oil per day. The Enterprise had a flare boom located on the starboard side (Figure 2) continuously burning gases coming up with the oil collected from the lower marine riser package atop the damaged BOP. One hundred eighty-six people were on board the Enterprise.



**FIGURE 2.** The Discoverer Enterprise from a transfer vessel.

In addition to using prior NIOSH HHE exposure data obtained for spill response workers to develop our industrial hygiene survey, we had to meet additional requirements to conduct this exposure assessment survey. All industrial hygiene equipment was required to be intrinsically safe; transportation by helicopter imposed space and weight considerations regarding amounts of equipment, and all equipment for our evaluation had to accompany us when we left shore. All personnel working offshore on the source control vessels were required to be quantitatively fit tested in full- and half-facepiece air-purifying respirators and have them in their possession. In the event contaminant levels on a source vessel rose to prespecified trigger levels, personnel had to have immediate access to and be able to use appropriate respiratory protection. This provided an opportunity to observe the respirator fit testing and individual respirator issue processes in use for all visitors to the source control vessels. Transportation safety requirements for all passengers to the source required completion of a training course in helicopter crash and open water survival before travel to the source could be scheduled.

## ASSESSMENT

NIOSH investigators conducted PBZ and area air sampling aboard the DD II on June 21, 2010, and aboard the Enterprise on June 23, 2010. A BP industrial hygienist and a Transocean health, safety, and environment advisor accompanied NIOSH investigators and helped facilitate the NIOSH evaluation.

Both vessels (the DD II and Enterprise) were in continuous operation 24 hr per day, 7 days per week, and workers on both vessels worked 12-hr shifts. We requested assistance identifying workers whose jobs required them to spend more time out on deck or working in areas of the vessel that had greater potential for exposure to volatile compounds associated with the crude oil.

Unlike crews and cleanup workers aboard vessels of opportunity, and volunteer cleanup workers onshore, the crews of the DD II and Enterprise were carrying out operations utilizing their normal work skills, routine personal protective equipment (PPE), training, and experience, i.e., well drilling aboard the DD II, and initial processing and storage of crude oil aboard the Enterprise. The only source of nonroutine occupational exposures aboard these vessels, that was identified by NIOSH investigators, was oil on the sea surface that had been released from the blown well.

To evaluate the presence of VOCs, NIOSH industrial hygienists conducted air sampling with (1) multisorbent TD tubes followed by TD/gas chromatography/mass spectrometry (NIOSH Method 2549),<sup>(10)</sup> and (2) activated charcoal tubes [NIOSH 1501 modified; NIOSH 1550].<sup>(10)</sup> Thermal desorption tube results were used to identify specific VOCs for quantitation in PBZ and area air samples collected using charcoal sorbent tubes. Other compounds measured in PBZ and/or area air samples using integrated air sampling techniques included propylene glycol ethers [NIOSH 1403 modified],<sup>(10)</sup>

**TABLE I. Sampling and Analytical Methods Used for Air Samples Collected Aboard Development Driller II and Discoverer Enterprise, June 21–23, 2010**

Analyte	Method
Benzene	NMAM <sup>A</sup> 1501 <sup>B</sup>
Carbon monoxide	Direct-reading —GasAlert CO Extreme <sup>C</sup>
Ethyl benzene	NMAM 1501 <sup>B</sup>
Glycol ethers (2-butoxyethanol, dipropylene glycol butyl ether, dipropylene glycol methyl ether)	NMAM 1403 <sup>B</sup>
Hydrogen sulfide	Direct-reading —GasAlert H <sub>2</sub> S Extreme <sup>C</sup>
Limonene	NMAM 1501 <sup>B</sup>
Naphthalene	NMAM 1501 <sup>B</sup>
Polynuclear aromatic hydrocarbons	NMAM 5506
Toluene	NMAM 1501 <sup>B</sup>
Total hydrocarbons	NMAM 1501 <sup>B</sup>
Volatile organic compounds (screening)	NMAM 2549
Xylenes, total	NMAM 1501 <sup>B</sup>

<sup>A</sup>NIOSH Manual of Analytical Methods.<sup>(10)</sup>

<sup>B</sup>Analysis for selected volatile organic compounds by an adaptation of the method.

<sup>C</sup>BW Technologies Ltd., Calgary, Canada.

and PAHs [NIOSH 5506].<sup>(10)</sup> Interest in 2-butoxyethanol and dipropylene glycol ethers occurred because their presence in dispersants used to break up oil released from the damaged well had been identified in earlier NIOSH work.<sup>(2,3)</sup> No dispersants were used or applied by workers aboard the DD II or the Enterprise.

Table I identifies the sampling and analytical methods used to evaluate the airborne contaminants. All sampling equipment was pre- and post-shift calibrated daily using representative sampling trains. Completed samples and field blanks were stored cold. Bulk sample analyses of the drilling mud (aboard the DD II) and crude oil from the MC252 Well No. 1 (collected by the Enterprise) were analyzed by sampling the headspace with TD tubes above the materials and as methylene chloride extractions. Methylene chloride extracts were transferred into gas chromatograph autosampler vials and injected directly into a gas chromatograph-mass spectrometer for analysis.

Job titles of sampled workers aboard the DD II were roustabout (5), floor hand (1), rotary floor foreman/lead floor hand (1), crane operator (1), and assistant driller (1). PBZ samples were collected during the 1200 to 2400 shift on June 21, 2010 (437- to 491-min sampling period). Area samples were collected at the lower moon pool, wire line deck, well test, and at a pipe manifold outside on the perimeter of the drill floor near the drill shack.

Full-shift PBZ air sampling was conducted aboard the Enterprise during the 0600 to 1800 shift on June 23, 2010. Job titles of sampled workers were well test field technician (1), floor hand (2), chief mate (1), fire technician (2), superintendent of remotely operated vehicles (ROVs) (1), electrician (1), motorman (1), and air monitoring technician (1). Duration of the PBZ samples was 304 to 771 min. The shortest duration samples were obtained for the floor hand job title PBZ samples that bridged a shift change. Area samples were collected at the moon pool and on the well test deck.

## RESULTS

Airborne concentrations for all contaminants evaluated on the DD II and the Enterprise were well below (<10% and often substantially less than 10% of) the lowest applicable OELs (identified in Table II<sup>(11–14)</sup>). Although the number of workers sampled was relatively small, samples were collected for workers thought to have the greatest exposure potential, i.e., working on open decks and directly involved with relief well drilling (DD II) or collecting oil coming through the riser from the damaged well (Enterprise).

Low concentrations of VOCs were detected on both vessels. The most abundant compounds identified were C<sub>10</sub>–C<sub>16</sub> aliphatic hydrocarbons. Other compounds detected in screening samples included ethylene glycol, 2-butoxyethanol, benzaldehyde, and phenol. Blank Sulfinert-treated tubes contained trace amounts of several contaminants. The ambient temperature and relative humidity (RH) reported for each vessel on the 2 days of exposure assessment was 84°F and 82% RH on June 21, and 85°F and 82% RH on June 23, 2010.

### Development Driller II (DDII)

PBZ air sampling results for nine workers on the DD II revealed that 69% (90) of the 130 analyses for specific contaminants were below detectable levels. Samples with detectable contamination had results ranging from below the minimum quantifiable concentration (MQC) to an amount that was quantifiable but very low. CO and H<sub>2</sub>S concentrations in PBZ samples were negligible (0–6 ppm CO) or zero (H<sub>2</sub>S). Four sets of area samples reflected the same proportion of nondetectable contaminants.

### Volatile Organic Compounds

Benzene, ethyl benzene, and naphthalene were not detected in PBZ or area air samples. Toluene was detected at a trace concentration (about 0.0012 ppm) below the MQC in an area air sample on the wire line deck. Toluene was not detected in any of the PBZ air samples. Xylenes were present below the MQC in two PBZ air samples for roustabouts on the main deck ( $\leq$  0.0031 ppm) and in the area air sample on the wire line deck (about 0.0040 ppm). Limonene was detected at 0.015 ppm in the PBZ of a floor hand on the rig floor, and below the MQC (about 0.0010 ppm) for a roustabout on the main deck. Limonene was not detected above the minimum detectable concentration (MDC) in the other two PBZ air

samples (rotary foreman/lead floor hand on the rig floor and a roustabout on the main deck). Limonene was present in a quantifiable concentration (0.032 ppm) on the wire line deck but was not detected in the area air sample at the pipe manifold. THC<sub>s</sub> were quantified in all PBZ and area air samples. PBZ air samples for THC<sub>s</sub> ranged from 0.5 to 1.1 mg/m<sup>3</sup>; the two area air samples had THC concentrations of 0.16 and 9.3 mg/m<sup>3</sup>. The highest THC concentration was measured on the wire line deck where several other area samples found detectable or quantifiable concentrations of other airborne compounds.

### 2-Butoxyethanol and Dipropylene Glycol Ethers

In the TD tube screening samples, 2-butoxyethanol was identified and subsequently quantified in some of the air samples. In four PBZ air samples, 2-butoxyethanol concentrations ranged from 0.029 to 0.28 ppm (two roustabouts, a floor hand, and a rotary foreman). The highest concentration was quantified in the sample collected on the rotary foreman while working on the rig floor. A review of drilling mud component material safety data sheets identified two drilling mud constituents with 2-butoxyethanol-containing materials (CAS 111–76–2).<sup>(15,16)</sup> The area air sample obtained on the wire line deck (above the rig floor) indicated 0.30 ppm; the area sample nearest to the ocean surface at the lower moon pool (below the rig floor) was below the MQC. Neither dipropylene glycol butyl ether nor dipropylene glycol methyl ether were detected in any of the PBZ or area air samples. These compounds were also absent in the drilling mud.

### Polynuclear Aromatic Hydrocarbons

Total PAHs (quantitated as naphthalene) in samples collected aboard DD II ranged from 0.0074 to 0.0096 mg/m<sup>3</sup> of air. Naphthalene (range: 0.00011–0.00094 ppm), phenanthrene (range: 0.0037–0.0074 mg/m<sup>3</sup>), and pyrene (range: 0.00046–0.001 mg/m<sup>3</sup>), were quantified in all five PBZ samples (roustabout, main deck (3); starboard crane operator; assistant driller, rig floor). Fluoranthracene was quantified (0.00014 mg/m<sup>3</sup>) in the sample collected for a roustabout on the main deck; fluorene was quantified in a sample collected for a second roustabout (0.00039 mg/m<sup>3</sup>) working the main deck and an assistant driller (0.00019 mg/m<sup>3</sup>) on the rig floor. Acenaphthene, acenaphthylene, fluoranthracene, and fluorene were present in three other workers' PBZs but below the MQC. A summary of the range of airborne concentrations for the different contaminants is presented in Table III. Table IV compares these contaminant levels with the most restrictive time-weighted average (TWA) OELs identified in Table II.

### Discoverer Enterprise (Enterprise)

PBZ air sampling results for 10 workers on the Enterprise showed that 67% (94) of the 140 analyses for specific contaminants were below detectable levels. Samples with detectable contamination had results ranging from below the MQC to a concentration that was quantifiable but very low. CO and H<sub>2</sub>S values were negligible (0–6 ppm for CO) or zero (H<sub>2</sub>S). In the two sets of area samples, 75% of the 20

**TABLE II. OELs for Substances Evaluated Aboard Development Driller II and Discoverer Enterprise, June 21–23, 2010**

Chemical	NIOSH REL	OSHA PEL	ACGIH TLV	AIHA WEEL
Benzene	0.1 ppm TWA 1 ppm STEL	1 ppm TWA 5 ppm STEL 0.5 ppm Action Level	0.5 ppm TWA 2.5 ppm STEL	N/A
2-Butoxyethanol	5 ppm TWA	50 ppm TWA	20 ppm TWA	N/A
Carbon monoxide	35 ppm TWA 200 ppm Ceiling	50 ppm TWA	25 ppm TWA	N/A
Dipropylene glycol butyl ether	N/A	N/A	N/A	N/A
Dipropylene glycol methyl ether	100 ppm TWA 150 ppm STEL	100 ppm TWA	100 ppm TWA 150 ppm STEL	N/A
Ethyl benzene	100 ppm TWA 125 ppm STEL	100 ppm TWA	100 ppm TWA <sup>A</sup> 125 ppm STEL	N/A
Hydrogen sulfide	10 ppm Ceiling (10 min maximum)	20 ppm Ceiling <sup>B</sup>	1 ppm TWA 5 ppm STEL	N/A
Limonene	N/A	N/A	N/A	30 ppm TWA
Naphthalene	10 ppm TWA 15 ppm STEL	10 ppm TWA	10 ppm TWA 15 ppm STEL	N/A
Polynuclear aromatic hydrocarbons	N/A <sup>C</sup>	N/A <sup>C</sup>	N/A <sup>C</sup>	N/A
Total hydrocarbons	350 mg/m <sup>3</sup> TWA 1800 mg/m <sup>3</sup> Ceiling (petroleum distillates)	2000 mg/m <sup>3</sup> TWA (Petroleum distillates as naphtha)	200 mg/m <sup>3</sup> TWA (Kerosene as total hydrocarbon vapor)	N/A
Toluene	100 ppm TWA 150 ppm STEL	200 ppm TWA 300 ppm Ceiling 500 ppm Peak (10 min maximum)	20 ppm TWA	N/A
Xylenes	100 ppm TWA 150 ppm STEL	100 ppm TWA	100 ppm TWA 150 ppm STEL	N/A

Notes: Shaded cells identify the TWA OEL applied (unadjusted for shift duration) to sampling results in Table IV. N/A, not applicable. REL = recommended exposure limit;<sup>(11)</sup> PEL = permissible exposure limit;<sup>(12)</sup> TLV = ACGIH threshold limit value;<sup>(13)</sup> WEEL = AIHA workplace environmental exposure level;<sup>(14)</sup> STEL = short-term exposure limit.

<sup>A</sup>Proposed to be changed to 20 ppm TWA and STEL eliminated.<sup>(13)</sup>

<sup>B</sup>Exposures shall not exceed with the following exception: if no other measurable exposure occurs during the 8-hr work shift, exposures may exceed 20 ppm, but not more than 50 ppm (peak), for a single time period up to 10 min.

<sup>C</sup>With the exception of naphthalene, OELs are not available for the individual PAHs measured in this evaluation.

contaminant-specific analyses were below detectable levels. Airborne concentrations of all sampled contaminants were well below relevant OELs for the samples collected aboard the Enterprise. Table III presents the range of airborne contaminant concentrations, and a comparison of contaminant concentrations with their respective OELs is shown in Table IV.

### Bulk Oil Samples

Major compounds identified in the headspace samples of the bulk crude oil were low molecular weight aliphatic hydrocarbons, mainly in the C<sub>5</sub>–C<sub>12</sub> range plus benzene, toluene, ethyl benzene, and xylenes. Major compounds identified in the bulk crude oil methylene chloride extraction solutions were higher molecular weight aliphatic hydrocarbons, mostly

C<sub>9</sub>–C<sub>30</sub> n-alkanes. Traces of PAHs were detected. The PAHs detected included naphthalene and alkyl naphthalenes (methyl-, dimethyl-, trimethyl isomers), C<sub>13</sub>H<sub>10</sub> fluorene plus alkyl analogs (methyl-, dimethyl-, trimethyl- isomers), C<sub>18</sub>H<sub>12</sub> isomer chrysene or benzo(a)anthracene plus alkyl analogs (methyl-, dimethyl- isomers), and C<sub>20</sub>H<sub>12</sub> isomers such as benzo(a)pyrene or benzo(e)pyrene.

### Volatile Organic Compounds

Charcoal tube air samples obtained on the Enterprise were quantitatively analyzed for the same compounds as described previously for DD II. Benzene, ethyl benzene, and naphthalene were not detected in PBZ or area air samples. Toluene and xylenes were detected at trace levels below the MQC (about

**TABLE III. Summary of Airborne Contaminant Concentrations Greater than the Minimum Detectable Concentrations**

Vessel	Contaminant	N	MDC <sup>A</sup>	Units	N >MDC	Range >MDC
DD II (06/21/10)	Benzene	6	0.001–0.003	ppm	0	—
	2-Butoxyethanol	6	0.0005–0.005	ppm	6	0.0062–0.30
	DGBE <sup>B</sup>	6	0.0007–0.007	ppm	0	—
	DGME <sup>C</sup>	6	0.0004–0.003	ppm	0	—
	Ethylbenzene	6	0.0009–0.002	ppm	0	—
	Limonene	6	0.0007–0.002	ppm	3	(0.0010)–0.032
	Naphthalene <sup>D</sup>	6	0.0008–0.002	ppm	0	—
	Naphthalene <sup>E</sup>	5	0.00002	ppm	5	0.00011–0.00094
	Total hydrocarbons	6	0.004–0.01	mg/m <sup>3</sup>	6	0.16–9.3
	Total PAHs <sup>F</sup>	5	0.0001	mg/m <sup>3</sup>	5	0.0074–0.0096
	Toluene	6	0.001–0.003	ppm	1	(0.0012)
	Xylenes	6	0.002–0.005	ppm	3	(0.0026)–(0.0040)
Enterprise (06/23/10)	Benzene	7	0.0008–0.003	ppm	0	—
	2-Butoxyethanol	7	0.0005–0.002	ppm	7	(0.0014)–0.032
	DGBE <sup>B</sup>	7	0.0009–0.003	ppm	2	(0.0017)–(0.0024)
	DGME <sup>C</sup>	7	0.0004–0.001	ppm	0	—
	Ethylbenzene	7	0.0006–0.002	ppm	0	—
	Limonene	7	0.001–0.002	ppm	4	(0.0011)–0.0097
	Naphthalene <sup>D</sup>	7	0.0005–0.002	ppm	0	—
	Naphthalene <sup>E</sup>	5	0.00001	ppm	5	0.00026–0.11
	Total hydrocarbons	7	0.003–0.009	mg/m <sup>3</sup>	7	0.080–0.13
	Total PAHs <sup>F</sup>	5	0.00007–0.0001	mg/m <sup>3</sup>	5	0.0048–0.020
	Toluene	7	0.0007–0.002	ppm	1	(0.0026)
	Xylenes	7	0.001–0.004	ppm	1	(0.0030)

Notes: Includes PBZ and area samples. Values in parentheses occur above the MDC but below the minimum quantifiable concentration (MQC). Parentheses indicate there is more uncertainty associated with these values than values above the MQC.

<sup>A</sup>MDC is a function of sample volume and the analytical limit of detection.

<sup>B</sup>Dipropylene glycol butyl ether.

<sup>C</sup>Dipropylene glycol methyl ether.

<sup>D</sup>Samples analyzed according to NIOSH method 1501 (modified).

<sup>E</sup>Samples analyzed according to NIOSH method 5506.

<sup>F</sup>Total PAHs quantitated as naphthalene.

0.0026 ppm and about 0.0030 ppm, respectively) in the PBZ air sample collected on the air monitoring technician but were below the MDC in the other four PBZ air samples: (1) fire technician, main deck; (2) well test field technician, production deck; (3) floor hands [two], rig floor; as well as the two area air samples (well test deck, moon pool). Limonene was quantified in three PBZ air samples: (1) fire technician, main deck; (2) air monitor technician; and (3) well test field technician, production deck; but was not detected in the other two personal samples (floor hand on rig floor [two]). Limonene was detected below the MQC on the well test deck (about 0.0011 ppm); limonene was not detected at the moon pool. THCs were quantified in all PBZ air samples on workers (0.08 to 0.42 mg/m<sup>3</sup>), and area air samples (0.08 mg/m<sup>3</sup>, moon pool; and 0.13 mg/m<sup>3</sup>, well test deck).

On the morning of June 23, 2010, the Enterprise encountered problems with the riser from the damaged well. The Discoverer disconnected from the lower marine riser package for a time and moved away from the well until the cause of the

problem was identified and corrected. NIOSH investigators were told that VOC levels might increase as a result of the increased release of crude oil from the BOP on the day of their exposure monitoring, but no such increase was evident in the sampling results.

#### *2-Butoxyethanol and Dipropylene Glycol Ethers*

Quantifiable concentrations of 2-butoxyethanol were measured in one floor hand PBZ air sample (0.032 ppm) and in the area air sample collected on the well test deck (0.0026 ppm). In the other four PBZ air samples (estimated at  $\leq 0.0022$  ppm) and in the area air sample at the moon pool, 2-butoxyethanol was below the MQC (about 0.0021 ppm). Dipropylene glycol butyl ether was detected below the MQC in PBZ air samples for the air monitor technician (about 0.0024 ppm) and the well test field technician on the production deck (about 0.0017 ppm). Dipropylene glycol butyl ethers were not detected in the other samples. Dipropylene glycol methyl ether was not detected in any of the samples.

**TABLE IV. Personal Breathing Zone Exposure Levels of Airborne Contaminants Compared with the Most Restrictive OEL (Unadjusted for Shift and Workweek Duration) for Contaminants with Specific OELs**

Vessel	Contaminant	# of PBZ	Average	Maximum	OEL <sup>A</sup>	Units
DD II (06/21/10)	Benzene (all ND) <sup>B</sup>	4	<0.001	<0.001	0.1	ppm
	2-Butoxyethanol	4	0.115	0.285	5	ppm
	Ethylbenzene (all ND)	4	<0.001	<0.001	100	ppm
	Limonene	4	0.004	0.015	30	ppm
	Naphthalene <sup>C</sup>	4	0.001	0.001	10	ppm
	Total hydrocarbons	4	0.854	1.133	200	mg/m <sup>3</sup>
	Toluene	4	0.001	0.001	20	ppm
	Xylenes	4	0.002	0.003	100	ppm
Enterprise (06/23/10)	Benzene (all ND)	5	<0.002	<0.002	0.1	ppm
	2-Butoxyethanol	5	0.008	0.032	5	ppm
	Ethylbenzene (all ND)	5	<0.001	<0.002	100	ppm
	Limonene	5	0.004	0.010	30	ppm
	Naphthalene <sup>C</sup>	5	0.001	0.001	10	ppm
	Total hydrocarbons	5	0.234	0.415	200	mg/m <sup>3</sup>
	Toluene (Trace and ND) <sup>D</sup>	5	≤ 0.002	≤ 0.003	20	ppm
	Xylenes (Trace)	5	≤ 0.003	≤ 0.003	100	ppm

<sup>A</sup>Lowest identified OEL from Table II.

<sup>B</sup>“(all ND)” indicates that all breathing zone samples for contaminant were below detectable levels; calculated value using limit of detection for each individual sample.

<sup>C</sup>Naphthalene not detected in breathing zone samples for the VOCs but was quantifiable in samples specific for PAHs.

<sup>D</sup>“≤” Values calculated using limit of detection (for ND) and limit of quantitation (for Trace) values for each sample.

### Polynuclear Aromatic Hydrocarbons

Five PBZ air samples were obtained for the chief mate (on the cargo deck), fire technician, superintendent of ROV (midship), electrician, and a motorman (on the lower machine deck). No PAH area air samples were collected. Total PAHs were calculated as the sum of all peaks present in the sample. The total PAHs for each sample were quantitated as naphthalene. Total PAHs ranged from 0.0048 to 0.020 mg/m<sup>3</sup> with naphthalene (range 0.00026–0.11 ppm), phenanthrene (range 0.0025–0.012 mg/m<sup>3</sup>), and pyrene (range 0.00050–0.0041 mg/m<sup>3</sup>), quantified in all five PBZ air samples.

Fluorene was quantified in the sample collected for the fire technician (0.00027 mg/m<sup>3</sup>) and was detected below the MQC (estimated to be ≤0.0002 mg/m<sup>3</sup>) in the other four PBZ air samples. Acenaphthylene was detected below the MQC (estimated to be ≤0.0008 mg/m<sup>3</sup>) in three PBZ air samples: (1) chief mate, cargo deck; (2) fire technician; and (3) superintendent of ROV, midship; and chrysene was found below the MQC (about 0.0004 mg/m<sup>3</sup>) in the electrician PBZ air sample.

### DISCUSSION

Exposure assessments at the source provided an opportunity to evaluate potential contaminants associated with the oil release. Work activities on the DD II and the Enterprise

involved operations typical of offshore oil well development and oil collection but were occurring in the context of the April 20, 2010, explosion and sinking of the Deepwater Horizon semi-submersible drilling rig that killed 11 workers and released an unprecedented amount of crude oil into the Gulf of Mexico.

One issue to consider in interpreting these findings is the fact that the results are compared to OELs unadjusted for actual work schedules. The source control vessels operated on 12 hr, 7-day per week schedules, with workers working 2 or 3 week-long rotations. Downward adjustment of the OELs, however, would not change the findings or determination for the days monitored in this evaluation due to the fact that all exposures were very low.

The NIOSH evaluation did not identify overexposures to contaminants that would necessitate routine wearing of respiratory protection; however, the immediate availability of respiratory protection is appropriate in this work environment because of the potential for an upset in operations, uncharacterized chemical releases, and sporadic releases of chemicals that may approach targeted action levels. Continuous onboard monitoring for contaminants of concern is a reasonable strategy for this situation.

NIOSH investigators noted two issues related to the respiratory protection program. The first was the use of only one manufacturer's line of respirators to fit all personnel. The

second issue was that a small number of workers observed on the vessels had facial hair that could interfere with the proper seal of a respirator. BP and Transocean representatives accompanying NIOSH investigators immediately noted the issues and initiated corrective actions.

## RECOMMENDATIONS

Although data collected on the days of the NIOSH evaluation did not indicate the need for mandatory, routine respiratory protection, the practice of having respirators immediately available for workers during uncontrolled situations or during operations where continuous area monitoring indicates rising exposure levels should continue.

The conduct of respiratory protection fit testing and issuance of air-purifying respirators at the Houma, Louisiana, heliport, as well as their adherence to BP respiratory protection program requirements, need to be reassessed and corrections implemented. The ability to adequately protect workers with one respirator line from one manufacturer is a questionable practice.<sup>(17)</sup> Identification and selection of alternate models of air-purifying respirators is needed. Although this does present challenges regarding respirator inventory and use, all workers need to be provided effective respiratory protection.

The respirator fit testing process provides a teachable moment for workers that should be better utilized. Information to be covered should include limitations of respiratory protection, proper donning and doffing procedures, indicators of the need for changing respirator cartridges, and proper storage and cleaning of respirators. Restrictions concerning facial hair and the ability to use air-purifying respirators should be reiterated to all workers where the potential to use respiratory protection is required. Although a worker may be clean-shaven on the day he reports to a source control vessel, he needs to maintain this status over the course of the 2–3 week work rotation aboard the vessel.

The appropriateness of applying unadjusted OELs to worker exposures obtained for 12 hr, 7-day per week work schedules should be re-evaluated for these operations. Consideration should be given to identifying the appropriate OELs for comparing full-shift exposures and for deriving action levels that trigger additional exposure reduction measures.<sup>(18)</sup> Transition from the current 2-week rotation to a 3-week rotation may have the potential to further complicate contaminant exposures. A review of offshore industry shift work noted there may be a potential for increased severity of injuries once shifts are extended beyond 12 hr in duration or tours of duty extended beyond the United Kingdom sector practice of 2 weeks.<sup>(19)</sup>

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