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Robert W. Dickey
U.S. Food and Drug Administration

Walton W. Dickhoff
National Oceanic and Atmospheric Administration

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Assessment of the potential impact of COREXIT® oil dispersants on seafood safety

Robert W. Dickey, Director Division of Seafood Science and Technology and Gulf Coast Seafood Laboratory, Center for Food Safety and Applied Nutrition, U.S. Food and Drug Administration, 1 Iberville Drive, Dauphin Island, AL 36528 USA

Walton W. Dickhoff, Director Division of Environmental Conservation, Northwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, 2725 Montlake Blvd East, Seattle, WA 98112 USA

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The April 20, 2010 explosion and subsequent sinking of the Deepwater Horizon oil production platform (DWH) resulted in the largest oil spill in U.S. history. On April 29th, a Spill of National Significance was declared as roughly 53 thousand barrels of oil per day flowed into the Gulf of Mexico (GOM). The U.S. Coast Guard estimated 4.9 million barrels of crude oil escaped before the damaged DWH wellhead was sealed on July 15, 2010 (National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling 2010). Oil spill clean-up methods included skimming operations, burning of surface oil, siphoning oil into tankers directly from the wellhead, and the application of chemical dispersants. The first 3 methods mentioned above physically removed spilled oil from GOM waters. The last method, chemical dispersion, distributed insoluble fractions of the oil into the water-column. This was done for 3 reasons: 1) to reduce the exposure of response personnel at-sea to volatile organic compounds emanating from the surface slick; 2) to prevent concentrated surface oil from reaching, and damaging, fragile coastal wetlands, beaches and shoreline communities; and 3) to accelerate the break-down of spilled oil by natural microorganisms in the environment. The oil spill response contingency plan (RCP) applicable to the GOM (EPA Regions 4 and 6 within the National Response Plan framework) pre-authorized the use of Nalco Co. (Naperville, IL) oil dispersants Corexit® 9527 and Corexit® 9500 among other pre-approved product formulations. From April 22 to July 19, 2010 an estimated 1.1 million gallons of Corexit® dispersant were applied over approximately 300 square miles of oiled surface waters in the GOM and 771,000 gallons were injected directly into the oil free-flowing from the wellhead 5,100 feet beneath the surface (National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling 2010). Corexit® 9527 comprised approximately 215,000 gallons (~11%) of the total dispersant volume applied to the surface oil slick and was discontinued on May 22. The unprecedented volume of chemical dispersants used to combat the DWH oil spill elicited public concerns for the health of responders, coastal communities, marine life, and the safety of seafood from impacted areas of the GOM. This document will address the latter of these concerns.

As part of the federal response to the DWH oil spill, the FDA and NOAA assessed dispersant ingredients for toxicity and potential to bioconcentrate in seafood species. With the exception of one proprietary component, the chemical compositions of Corexit® 9527 and Corexit® 9500 were identified in material safety data submitted to EPA as required by subpart J of the National Contingency Plan (NCP), Sec. 300.915 for RCP pre-authorization

(U.S. Environmental Protection Agency, 2010a). As it became apparent that large volumes of dispersants were being used to combat the subsurface and surface oil spill, EPA requested and received from the manufacturer disclosure of the proprietary component (i.e. dioctyl sodium sulfosuccinate, DOSS). Corexit® constituents are listed in Table 1 and described below.

Table 1.

CAS No.	Name	Corexit® 9527	Corexit® 9500
111-76-2	2-Butoxyethanol (ethylene glycol mono-n-butyl ether)	X	
57-55-6	Propylene glycol	X	X
29911-28-2	Dipropylene glycol monobutyl ether	X	X
577-11-7	Dioctyl sodium sulfosuccinate	X	X
64742-47-8	Petroleum distillates, hydrotreated light fraction		X
1338-43-8	Sorbitan, mono-(9Z)-9-octadecenoate	X	X
9005-65-6	Polyoxy-1,2-ethanediyl derivatives of sorbitan, mono-(9Z)-9-octadecenoate	X	X
9005-70-3	Polyoxy-1,2-ethanediyl derivatives of sorbitan, tri-(9Z)-9-octadecenoate	X	X

The solvent 2-butoxyethanol is a high production glycol ether and constituent of Corexit® 9527. It has other common uses as a solvent and degreaser in industrial, residential and personal care products including protective surface coatings (spray lacquers and paints), agricultural chemicals, household cleaners, and liquid soaps and cosmetics at concentrations of up to 10%. This compound is approved by FDA as an indirect and direct food additive for use as a antimicrobial agent, defoamer, stabilizer and component of adhesives (21 CFR 175.105(FAP 1B0233); 178.1010(FAP 4A1375); 176.210(FAP 3B0899); 177.1650; 173.315(FAP 5A3079); U.S. National Archives and Records Administration's Electronic Code of Federal Regulations, <http://www.gpoaccess.gov/ecfr>). FDA approval means that the compound is safe for its approved intended uses and the human exposures associated with those uses. 2-butoxyethanol has been well studied. Information is available on metabolism, mechanism of toxicity, pharmacokinetics and impact of exposure on human health. Principal routes of human exposure are inhalation and dermal exposure. Primary effects are on the hematologic system with secondary renal effects. Acute oral LD₅₀ values in a variety of rodent animal models range from 200 to 12,750 mg/kg bw. The Agency for Toxic Substances and Disease Registry (ATSDR) derived a minimal risk level (MRL¹) of 0.4 mg/kg bw d⁻¹ for human acute-duration (14 days or less) oral exposure. Acute oral exposures of humans to large amounts of 2-butoxyethanol have been shown to cause coma and respiratory depression in addition to hematotoxic effects, although this route of exposure is the least likely for the general population. From quantitative structure-activity relationships,

¹ An MRL is defined as an estimate of daily human exposure to a substance that is likely to be without an appreciable risk of adverse effects (noncarcinogenic) over a specified duration of exposure. MRLs are derived when reliable and sufficient data exist to identify target organs(s) of effect or the most sensitive health effects(s) for a specific duration within a given route of exposure. MRLs are based on noncancer health effects only and do not reflect a consideration of carcinogenic effects. MRLs can be derived for acute, intermediate, and chronic duration exposures for inhalation and oral routes.

the bioconcentration factor (BCF) for 2-butoxyethanol in fathead minnows (*Pimephales promelas*) has been estimated to be 2 (ATSDR). The biodegradation half-life of 2-butoxyethanol in surface waters is estimated to be in the range of 7-28 days, and the chemical is likely readily biodegraded in aerobic soil and water (National Institutes of Health, Hazardous Substances Data Bank, 2010).

The solvent dipropylene glycol monobutyl ether is an isomeric mixture and constituent of both Corexit® 9527 and 9500. Other common uses include as a solvent for industrial and residential cleaners/degreasers, paints and plasticizers. Propylene glycol ethers as a class are rapidly absorbed and exhibit low acute toxicity by oral exposure. Acute oral LD₅₀ values in rodents range from 3 to 5 g/kg bw and repeated dosing (13-week) studies suggest a no observable adverse affect level of 450 mg/kg bw d⁻¹. The calculated BCF is 1.47 indicating low potential for bioaccumulation. Propylene glycol ethers are unlikely to persist in the environment. In water, propylene glycol ethers are readily biodegradable under aerobic conditions (OECD 2003; National Institutes of Health, Hazardous Substances Data Bank, 2010).

Propylene glycol is a constituent of both Corexit® 9527 and 9500. Other common uses include commercial formulations of foods, drugs, cosmetics, and personal care products (e.g. toothpaste, shampoo, mouthwash). Propylene glycol is approved by FDA as a Generally Recognized As Safe (GRAS) ingredient, direct food additive, and indirect food additive for many uses, including as an anticaking agent, antimicrobial agent, antioxidant, color or color adjunct, defoamer, dough strengthener, emulsifier, flavoring agent, formulation aid, humectant, processing aid, solvent, diluent or vehicle stabilizer, thickener or gelling agent, surfactant, and texturizer (21 CFR 175.105(FAP 1B0233, FAP 2B0650); 178.3300; 175.300; 175.320; 177.2420; 177.1680(FAP 5B1808); 184.1666; U.S. National Archives and Records Administration's Electronic Code of Federal Regulations). Oral exposure of humans to propylene glycol is infrequently associated with adverse effects. Acute oral LD₅₀ values in a variety of rodent animal models range from 18 to 46 g/kg bw (National Institutes of Health, Hazardous Substances Data Bank, 2010). Some acute oral data exist for humans, but the information is limited and includes systemic and neurological effects at high levels of exposure. No MRLs for oral exposure to propylene glycol in humans have been derived by ATSDR because data are insufficient. The FAO/WHO Joint Expert Committee on Food Additives (JECFA) determined 25 mg/kg bw d⁻¹ as the acceptable daily intake (ADI) for propylene glycol (FAO/WHO, 1997). The calculated BCF is 3 indicating a low potential for bioconcentration and bioaccumulation. Propylene glycol is unlikely to persist in the environment. In water, propylene glycol is readily biodegradable under aerobic conditions (OECD 2003; National Institutes of Health, Hazardous Substances Data Bank, 2010).

Petroleum distillates, hydrotreated light fraction are paraffinic dearomatized, and volatile solvents derived from crude petroleum, and constituents of Corexit® 9500. Other common uses include as a solvent for paints, varnishes, polishes, and lubricants, and general purpose cleaners and degreasers. FDA has approved similar odorless light petroleum hydrocarbons as indirect and direct food additives (21 CFR 172.884; 175.105; 176.200; 176.210; 178.3650; U.S. National Archives and Records Administration's Electronic Code of

Federal Regulations). Acute oral LD₅₀ values in rodent animal models are greater than 5 g/kg (National Institutes of Health, Hazardous Substances Data Bank, 2010). The calculated BCF ranges from 60 to 80 indicating low potential for bioconcentration and bioaccumulation. Petroleum distillates are volatile and unlikely to persist in the environment. In water, petroleum distillates are readily biodegradable under aerobic conditions.

Dioctyl sodium sulfosuccinate (DOSS) is an anionic surfactant (butanedioic acid, 2-sulfo-1,4-bis(2-ethylhexyl) ester, sodium salt) listed as a proprietary organic sulfonic acid salt constituent of both Corexit® 9527 and 9500 formulations. Other common uses include wetting and flavoring agent in food, industrial, and cosmetic applications, and a medicinal stool softener in over-the-counter use (e.g., docusate). FDA has approved this compound as a GRAS ingredient, and as indirect and direct food additives under prescribed conditions of use (21 CFR 73.1; 131.130; 133.124; 133.133; 133.134; 133.162; 133.178; 133.179; 163.117; 168.115; 172.520; 172.808; 172.810; 175.105; U.S. National Archives and Records Administration's Electronic Code of Federal Regulations). JECFA determined 0.1 mg/kg bw d⁻¹ as the ADI for dioctyl sodium sulfosuccinate (FAO/WHO, 1995). The calculated BCF is 10 indicating a low potential for bioconcentration and bioaccumulation. DOSS is nonvolatile from water (Henry's law constant 5×10^{-12} atm m³/mol) and several studies have reported >90% biodegradation in 3-12 days at freshwater concentrations of 3.3-12.9 ppm (National Institutes of Health, Hazardous Substances Data Bank, 2010).

The nonionic surfactant Span 80 (CAS No. 1338-43-8) is a trade name for sorbitan, mono-(9Z)-9-octadecenoate. The nonionic surfactant Tween 80 (CAS No. 9005-65-6) is a trade name for a mixture of isomers and congeners of polyoxy-1,2-ethanediyl derivatives of sorbitan, mono-(9Z)-9-octadecenoate. The nonionic surfactant Tween 85 (CAS No. 9005-70-3) is a trade name for a mixture of isomers and congeners of polyoxy-1,2-ethanediyl derivatives of sorbitan, tri-(9Z)-9-octadecenoate. Numerous chemical synonyms and trade names are used for these materials. Other common uses for Span and Tween products include as wetting agents, solubilizing agents, or emulsifying agents in cosmetic and personal care products. Span 80 and Tween formulations are widely used in food products, oral pharmaceuticals, and parenteral products. They include GRAS ingredient and direct and indirect food additives commonly known as polysorbates (21 CFR 73.1; 107.105; 172.515; 172.623; 172.836; 172.838; 172.840; 172.842; 173.310; 173.340; 175.105; 178.340; U.S. National Archives and Records Administration's Electronic Code of Federal Regulations). JECFA specifies 25 mg/kg bw d⁻¹ as the ADI for Tween 80 and Span 80 (FAO/WHO, 1973).

The aquatic toxicity of dispersant formulations has been examined and debated over many years. Following extensive reviews in 1989 and 2005, and suggested standardization of testing methods, dispersants in use today are generally reported to be less toxic than formulations prior to 1970 (e.g. NRC 1989, 2005, Fingas 2002). Corexit® dispersants in particular have been well studied with most reports indicating lower aquatic toxicity in direct comparisons with water soluble, water accommodated and chemically dispersed oil fractions (e.g., George-Ares and Clark, 2000; Liu et al., 2006; Hemmer et al., 2011). Other studies have addressed dispersant influence on the bioavailability and uptake of aromatic

and aliphatic constituents of oil by various aquatic species (e.g. Milinkovitch et al., 2011; Mielbrecht et al., 2005; Fuller et al., 2004; Ramachandran et al., 2004; Singer et al., 1998). However, the potential for dispersant constituents themselves to accumulate in aquatic species has received less attention. Several studies investigating uptake and disposition of principal dispersant constituents, ionic and nonionic ethoxylate surfactants, in aquatic species suggest rapid uptake, metabolic conjugation, concentration in liver and bile with transient enterohepatic circulation, and rapid elimination (Alvarez-Munoz et al., 2010; Tolls et al., 2000; Tolls & Sijm 1999; Goodrich et al., 1991; Granmo & Kollberg 1976; Calamari & Marchetti 1973). Distribution of surfactants into muscle tissues was reported to be low order with commensurate and low BCF values for edible tissues. In one of few studies to assess the uptake and disposition of Corexit® constituent dioctyl sodium sulfosuccinate in aquatic species Goodrich et al. (1991) noted rapid uptake and concentration in viscera and bile of rainbow trout, at significantly higher levels than uptake in either blood and carcass. BCF were not determined for viscera or bile due to the lack of steady state conditions but for blood or carcass compartments BCFs of 3.47 and 3.78 were derived indicating little bioconcentration in edible tissues.

The initial federal chemical safety assessment of Corexit® dispersants in the context of seafood safety included structure-activity modeling to estimate BCFs for Corexit® constituents. Predictive BCFs for Corexit® constituents, other than the nonionic ethoxylate surfactants and light petroleum distillates, fell below 10 L/kg suggesting low potentials for bioconcentration and accumulation in edible tissues of aquatic species. The BCFs for light petroleum distillate mixtures ranged from 60 to 80 L/kg. Nonionic ethoxylate surfactant BCFs have been experimentally determined in fathead minnow with an average value of 39.6 L/kg and maximum value of 387 L/kg suggesting moderate potential for bioconcentration (Tolls et al., 2000). Dispersant concentrations in DWH surface applications at sea were estimated by the manufacturer to be approximately 30 µg/L in the area of the oil slick to a depth of 10 meters (Nalco, 2010), and rapidly diluted and biodegraded in the ocean environment to levels below detection (Georges-Ares & Clark, 2000; National Research Council, 1989). Analyses for Corexit® constituents in surface water and sediment samples from across the GOM after dispersant applications had ceased did not detect dispersant chemicals above limits of detection (U.S. Environmental Protection Agency, 2010b). However, offshore and deep subsurface sampling and analyses revealed trace levels (12 ppb) of principal constituent DOSS entrained in a hydrocarbon plume at 1000-1200 m water depth (Kujawinski et al., 2011).

In the development of a method for surveillance of dispersant residues in GOM seafood species the FDA and NOAA performed controlled exposures of Corexit® 9500 to live Eastern oyster (*Crassostrea virginica*), blue crab (*Callinectes sapidus*), and red snapper (*Lutjanus campechanus*) to generate incurred residues (Benner et al., 2010). DOSS was selected as the most appropriate indicator compound for potential Corexit® contamination in seafood due to its inclusion in both Corexit® formulations, OTC medicinal use, extremely low volatility, and potential to persist in the environment longer than other dispersant components (National Institutes of Health, Hazardous Substances Data Bank, 2010). The laboratory exposure studies were designed to generate incurred residues in seafood species to support method development and validation under a compressed time

schedule, and therefore procedural design was not intended to be sufficient for rigorous pharmacokinetic assessment and environmental relevance. Nevertheless, it was possible to incorporate a limited sampling of uptake and depuration time points in the species exposed.

Performance testing of a rapid extraction procedure and liquid chromatography tandem mass spectrometry (LC-MS/MS) method for DOSS showed an average recovery of 92% and relative standard deviation of 11%. The method limits of detection (LOD) for DOSS in seafood species ranged from 0.003 µg/g (FDA Forensic Chemistry Center) to 0.015 µg/g (NOAA Northwest Fisheries Science Center) and limits of quantitation (LOQ) from 0.010 µg/g to 0.045 µg/g (Flurer et al., 2011). Mean DOSS concentrations in laboratory exposed and depurated oysters exposed to 100 mg/L Corexit® 9500 were 18 and 12 µg/g after 24 and 48 h of exposure, respectively. Levels of DOSS declined by >99%, to 0.023 µg/g within 72 h of depuration in clean water. In crabs exposed to Corexit® 9500 (100 mg/L) for 24 h, mean DOSS levels in muscle was 0.9 µg/g with levels declining to 0.023 µg/g (>97%) within 72 h of depuration in clean water. After 24 h of exposure, mean DOSS concentration in crab hepatopancreas was 11 µg/g, more than 10-fold higher than corresponding muscle tissue. Levels increased initially during the first 24 h of depuration, possibly as a result of the re-distribution of residues within the body during elimination. Levels subsequently declined >95% to 2.4 µg/g after 72 h of depuration. DOSS concentrations in muscle tissues of red snapper exposed to 100 mg/L Corexit® 9500 for 24 h were near (0.015 ppm) or below the LOQ at all sampling times (Benner et al., 2010).

In retrospective analyses of 393 GOM fisheries re-opening samples collected from June 2010 through March 2011, DOSS was not detected in 116 of 119 samples collected from State waters. Three samples from State waters showed DOSS levels ranging from 0.011 to 0.013 µg/g. Of 274 samples analyzed from Federal waters, 12 finfish samples contained DOSS ranging from 0.037 to 0.41 µg/g. Overall, DOSS was detected at or above the LOQ in less than 3.6% (14/393) of the re-opening samples tested and all were below safety thresholds determined for DOSS in finfish, shrimp, crabs, and oysters (FDA, 2010a, b)

Conclusions:

In considering the potential for chemical dispersants to compromise the safety of GOM seafood, initial questions concerned the potential toxicity of dispersant constituents, their concentrations and persistence in the environment, their potential for bioconcentration in seafood species, and their disposition and persistence in seafood species. With the exception of dipropylene glycol monobutyl ether, the constituents of Corexit® dispersants are recognized direct or indirect food additives under prescribed conditions of use. Corexit® dispersants used to treat the DWH oil spill were rapidly and extensively diluted in GOM waters, and environmental concentrations estimated and measured, were commensurately low (i.e. ppb) when detected. The physicochemical characteristics and scientific literature indicate that the dispersant constituents are susceptible to chemical and biological degradation, and that the potential for bioconcentration and persistence in the edible tissues of seafood species is low. The modeling, experimental and field assessments performed during the response to the DWH oil spill, as well as ancillary literature, indicated that Corexit® dispersants did not pose a threat to the safety of GOM seafood during or after their use. Oil spills in different parts of the world are known to differ in the

nature and extent of public and environmental health hazards entailed, and consequently response strategies are rarely the same. There are numerous dispersant formulations available or in development for mitigation of oil spills under different physical conditions. Future responders would benefit from a systematic assessment of less known dispersant constituents, and their fate in aquatic species.

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