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Analysis of Potential for Human Exposure to Aerial Dispersant Application

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ABSTRACT

The response to the Macondo oil well blow-out in the Gulf of Mexico in 2010, utilized significant quantities of dispersants. The way dispersants make oil available to natural biodegradation, their environmental effects, and overall benefits in oil spill reponse were well understood by the oil and spill response industries. These materials have been studied and improved for over 40 years. In spill response scenarios like Macondo, the large quantities of dispersant utilized raised concerns regarding human exposures.

This paper provides the following:

- An analysis of dispersant spray drift from aerial application of oil dispersant.
- A review of the exclusion zones established by the Region IV and VI Regional Response Teams (RRT's).
- Evidence that the controls to protect cleanup workers were effective.

The volume of chemical dispersant utilized in the Macondo response is often presented as an indicator suggesting human exposure. While the volume is interesting, the application, its dilution in the water column, and its environmental persistence are far better measures of the potential for human exposure. Furthermore, the controls that were required by the Federal–On-Scene-Coordinator to ensure responder and public safety are critical considerations. These controls were designed and implemented by Regulators and supported by appropriate health

professionals to avoid the possibility of human exposure. These controls were established and published well before the Macondo spill.

Studies were undertaken during the 2010 spill response to examine surface and subsurface waters to determine the presence of dispersant constituents. Spill response worker exposure was evaluated in both offshore and on-shore clean-up areas during dispersant application. The studies found no evidence that response workers were exposed to levels of constituents that approached occupational exposure limits.

INTRODUCTION

In response to the 2010 Deepwater Horizon oil well blow-out in the Gulf of Mexico, about 973,000 gallons of oil dispersants were used at the water surface (Houma ICP Aerial Dispersant Group, 2010). Dispersants are spread onto oil on the water surface using spray nozzles from either vessels or aircraft. Oil dispersants are composed of surfactants that are mixed into a hydrocarbon solvent. This solvent is used as a carrier for the surfactants to introduce the surfactant molecules into the oil matrix as it floats on the water's surface. The surfactant then combines with oil to reduce the oil's surface tension and form small droplets (<100 um) that have a negligible rise velocity in water. This allows the oil droplets to mix into the water column as a result of wave and current (e.g. Langmuir) actions.

The design evolution of dispersants has been toward constituents of lower toxicity and higher efficacy. The primary EPA approved dispersant used during the Deepwater Horizon response was COREXIT 9500. Dispersants are well understood in the oil spill response community as the science behind their development, use, and environmental and human health effects spans more than 40 years. The oil dispersant COREXIT 9500 was specifically designed to address the limitations of previous dispersants that had a limited window of opportunity on spills of weathered and heavy oils. The resulting surfactant and solvent combination for COREXIT 9500 was tested and selected to expand the window of opportunity and reduce environmental toxicity.

The analysis presented here considers the potential for human exposure from dispersant application by aircraft, the primary means by which dispersants were applied at the water surface. We examine the potential for migration of aerosols under the extremes of wind conditions under which dispersants were applied during the response. The goal of this analysis is to improve the general understanding of dispersant application, the procedures that were in place to prevent human exposure, and to present estimates of dispersant transport under the range of application conditions.

METHODS

Dispersants can be applied from vessels, helicopters, and a variety of aircraft. For the purpose of this analysis, the largest dispersant aircraft utilized in the Deepwater Horizon response, a Lockheed C-130, is considered. There were 8 military or civilian configurations of this aircraft utilized in the Macondo response. These aircraft were responsible for the application of 82% of the dispersant applied aerially (Houma ICP Aerial Dispersant Group, 2010). While there were variations in dispersant capacity, nozzle number, and set-up, they all had an equivalent oil dispersant application rate in common, e.g. uniform application of about 5 gallons/acre. In order to examine the potential human exposure from spray drift, the largest Lockheed C-130 (L382 civilian designation) configuration will be considered. This aircraft has 64 spray nozzles, and carries about 5000 gallons of dispersant, the largest volume of dispersant among the aircraft utilized. The analysis of the spray drift was performed utilizing AGDISP, a USDA Forest Service Spray Modeling Software (V 8.28). AGDISP is a science-based model that predicts spray drift from a variety of application platforms. The model was developed by the USDA Forest Service. AGDISP was designed to optimize agricultural spraying operations and has detailed algorithms for characterizing the release, dispersion, and deposition over and downwind of the application area. This model can be used in estimating downwind deposition of spray drift from aerial and ground boom applications (AGDISP, US Forest Service).

The Lockheed C-130 aircraft and its operational parameters are in the software's library of aircraft. Other key model parameters, such as application altitude, number and distribution of spray nozzles, spray swath width, spray droplet size distribution, volatility and specific gravity of the applied solution were determined from studies that examined aerial application results and dispersant fate. Meteorology, surface roughness, and atmospheric stability, are variables that were specific for the range of conditions experienced during the Deepwater Horizon oil spill response. Operationally the parameters in Table 1 represent the conditions that were utilized in the AGDISP model.

Table 1. AGDISP Model Parameters

AGDISP Model Parameters	
Application Method	Aerial spraying at 100 feet altitude

Application Technique	Nozzles 30 per side on 25% of wing (Model limit is 30, plane has 32 nozzles/side)
Droplet Size Distribution	Average $D_{v0.5}$ 578 um , Relative Span ($D_{v0.9}$-$D_{v0.1}$/$D_{v0.5}$) 1.07
Meteorology	Temp 85^{o}F, Relative Humidity 90%
Wind Speed	3 mph and 35 mph, represents likely extremes of wind conditions
Spray Material	COREXIT 9500, non-volatile, 5 gal/acre application rate
Atmospheric Stability	Stable
Surface	No canopy, surface roughness - minimum setting
Advanced Settings	Specific Gravity 0.79, Evaporation Rate 2.47 sq. um/Deg C/sec
Aircraft Direction	Aircraft flies North with wind from West
Timing	During daylight hours
Visibility	3 nautical miles

Several of the key parameters utilized in the model will be examined in greater detail before considering the modeling results. The droplet size distribution is one of the key parameters that are important to the transport of dispersant spray. The reason for this is that larger droplet size will produce a greater mass which affects the droplet's fall to the oil surface. The greater the droplet's mass, the less it will be affected by cross winds. Conversely, the smaller the droplet size and mass, the easier it will be affected and moved by a cross wind. A study, performed at the request of the Marine Spill Response Corporation (Reynolds, 2012), examined droplet size distribution, the swath width, and application rate for the C-130 and several additional aircraft. The aircraft spread water onto water sensitive cards placed onto the ground. The C-130 test had 4 replicate runs and produced the results provided in Table 2. This information produces direct model inputs for droplet size distribution. The swath width and application rate are well in line with the expected values.

Table 2. C-130 Test Results

C-130 Test Results	
Average $D_{v0.5}$	578 um
Relative Span $(D_{v0.9}-D_{v0.1}/D_{v0.5})$	1.07
Average Swath Width	145 feet
Average Application Rate	5.5 gallons/acre

A second key piece of information is the volatility of the COREXIT 9500 droplet. If the droplets that are released from the aircraft are highly volatile, they will lose size and mass as they fall and become more susceptible to transport by cross winds. This issue is further important because the droplets are being sprayed from an aircraft traveling at least 150 knots (Knot = 1 nautical mile/hour or 1.15 statute miles/hour). This question was examined and reported by Ebert et al. (2008). Droplets of COREXIT 9500, COREXIT 9527, and water at sizes of 100um, 500um, and 1000um were examined. The COREXIT 9500 exhibited no droplet size reduction for the 500um and 1000 um droplets, and a slight reduction for 100um droplets. Since the average droplet size for spray from a C-130, was already reported as slightly greater than 500um, the evaporation rate of COREXIT 9500 was set to a minimum in the spray model analysis. This study also examined the evaporation of droplets at various conditions over 20 minute time periods. The losses from COREXIT 9500 were approximately 1-2% over that time further reinforcing the zero loss of mass when being applied from an aircraft over water.

The final parameter to consider is the direction of the aircraft. In spraying dispersants with this large aircraft, the preferred direction of flight is directly into the wind. Aircraft that are applying pesticides to rows of plants may wish to align with those rows and the crosswinds serve to shift the alignment of the spray based upon the wind's direction. Aircraft spraying dispersant on oil have no need to fly with a crosswind. The configuration of oil slicks is often elongated as a result of wind action, so flying into the wind can align the aircraft's path along the long axis of the slick. As a result, the dispersant is not typically shifted to the right or left as a result of a crosswind. The AGDISP model does not provide for aircraft flying directly into the wind. As a result, the surface winds were modeled as a right angle crosswind. This serves to produce a highly conservative prediction of dispersant drift from the axis of the flight path relative to operational conditions.

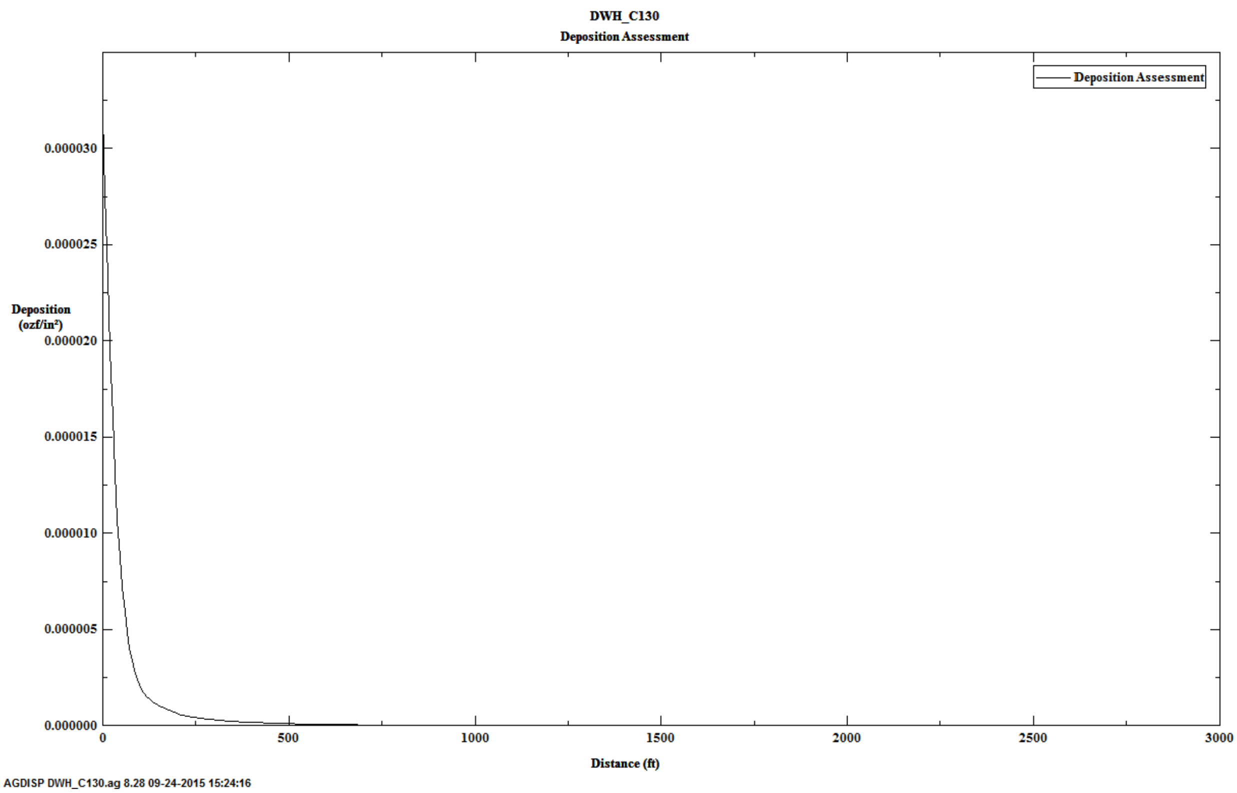
RESULTS/DISCUSSION

AGDISP Model Output

The AGDISP Model output of primary interest in this analysis is the downwind travel of dispersant spray under the extremes of wind conditions experienced during Deepwater Horizon spill response aerial dispersant application. This output is identified as the Deposition

Assessment and is reported as fluid ounces/inch^2. The deposition assessment for the 3 mph crosswind from -90^o (270^o or wind from West), is presented in Figure 1.

Figure 1. Deposition of COREXIT 9500 when sprayed from a height of 100 feet with a 3 MPH Crosswind



The goal of dispersant application from the C-130 aircraft is to treat a swath of oil about 150 feet wide. This plot demonstrates that the majority of the dispersant spray is deposited within about 125 feet of the flight line with the slight cross wind. When flying into any wind, this plot presents the potential distance that dispersants might move downwind from the application point. When the model is run with a 35 MPH crosswind from the west, the spray drift is shifted further away from the line of flight. The results of that model run are presented in Figure 2.

Figure 2. Deposition of COREXIT 9500 when sprayed from a height of 100 feet with a 35 MPH Crosswind

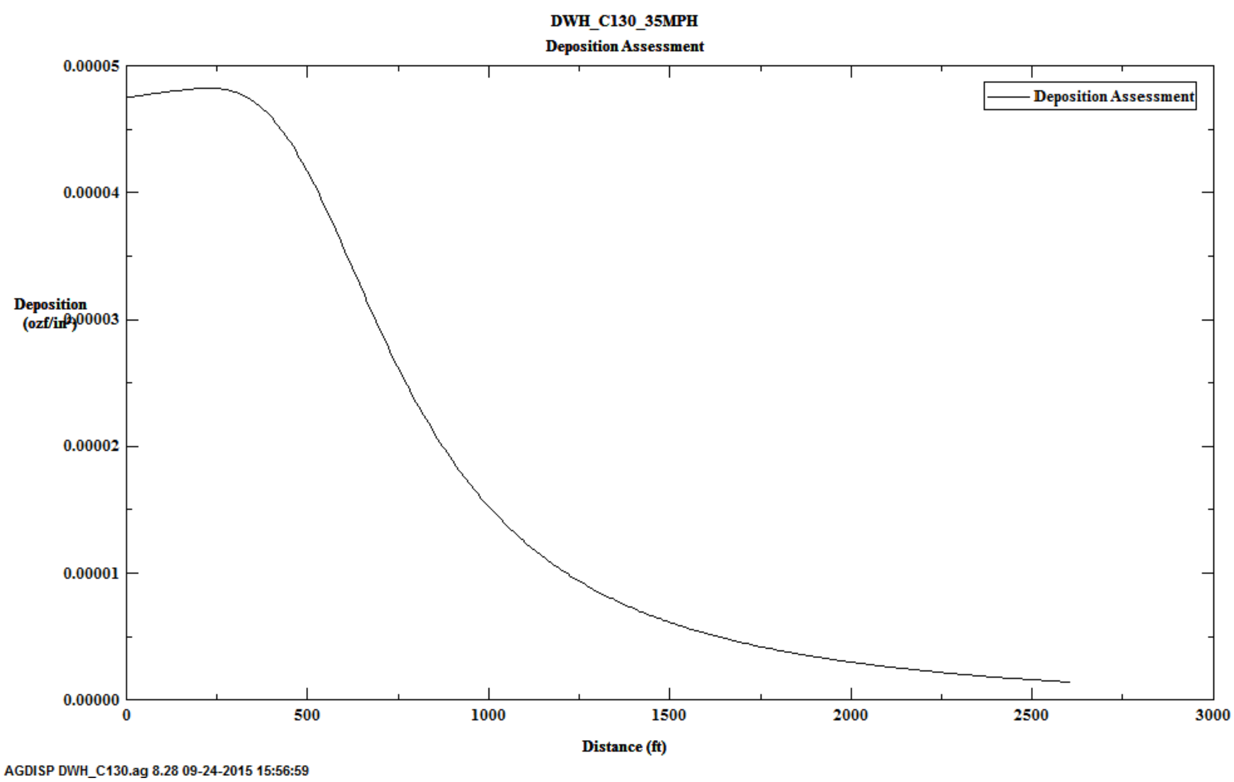


Figure 2 clearly demonstrates the effect of a cross wind from the West. The swath of the dispersant spray would be shifted much farther to the East of the flight path. However even with this significant cross wind, the volume of spray approaches 0.0 at about 2500 feet (about 0.5 nautical miles) from the flight path. When considered from the perspective of the additional wind when the aircraft flies into the wind, this plot demonstrates a minimal potential downwind transfer of dispersant. The Regional Response Teams for Gulf Coast Regions 4 and 6, established protocols for dispersant application well before the Deepwater Horizon spill. Exclusion zones ranging from 2 to 3 nautical miles (nm) from shorelines, surface vessels, and marine mammals were established (Fact Sheet No.5, Oil Spill Prevention). This analysis of spray drift demonstrates that even under highly unlikely cross wind conditions, the protocol for dispersant spraying was protective of shorelines, vessels, and key environmental species using the exclusion zones that were established by the RRT.

Discussion

Oil dispersants utilized in the Deepwater Horizon spill response were specifically designed to have low potential for toxicity, as demonstrated in COREXIT' s Safety Data Sheet (Nalco, 2012). Very few responders would have been potentially exposed to the undiluted dispersant material; King and Gibbins, 2011, reported that workers handling neat dispersant received training and were observed using personal protective equipment (PPE) to minimize exposure.

Dispersants are spread onto oil at the water surface using spray nozzles from either vessels or aircraft. The black oil that is typically targeted for response is approximately 0.1 mm in thickness. Once spilled, oil spreads very rapidly ($10m^2$/sec) in open offshore waters. This is as a result of both gravity spreading and advection resulting from the actions of winds and currents. The propensity of oil to thin on the surface of the water is one of the primary reasons that dispersant application is a desired technology for spill response. The area that can be treated from large aircraft is up to 10X larger than the area that can be mechanically skimmed using a boom and vessel combination during the same time period. Furthermore, the environmental wind and wave conditions for effective skimming are far more restrictive than those under which dispersants can be effectively applied.

Dispersants are typically applied to black oil at a rate of about 5 gallons/acre or 5 ml/m^2. The desired application rate for dispersants is a ratio of 1:20, or 1 part dispersant to 20 parts oil (Oil Spill Response Field Manual, 2014). The 0.1mm thickness of black oil noted earlier, results in a volume of 100 ml/m^2 of oil. This meets the desired goal of the 1:20 ratio of dispersant to oil as well as the 5 ml/m^2 application rate for dispersants. This also provides the ability to quickly estimate the amount of dispersant in the water column once it is mixed. A dispersant applied at 5 ml/m^2, will produce a concentration of approximately 5 ml/m^3, or 5 about ppm when mixed in the upper 1 meter of the water column. This concentration is a key value to consider when evaluating studies of the effects from dispersant exposure. Dispersed oil mixing into the upper meter of the water column occurs within minutes. It is also important to remember that dilution of dispersed oil does not end at 1 meter of depth. The concentration at 1 meter depth simply provides a convenient basis for comparison of study data and endpoints.

The measurement of dispersant constituents in the water can serve as a validation that dispersants were applied at the rates proposed. The concentration of dispersants in Gulf of Mexico waters during 2010, was measured by the USEPA in their water testing program

(Johnson et al., 2012). The study results showed that none of more than 600 water samples collected contained DSS concentrations greater than the 20 ug/L reporting limit for the analysis.

The volume of chemical dispersant utilized in the Deepwater Horizon response is often presented as an indicator for human exposure. However, the controls that were required by the Federal–On-Scene-Coordinator to ensure responder and public safety are critical considerations. These controls were designed and implemented by Regulators and supported by appropriate health professionals to avoid the possibility of human exposure. These controls were established well before the Deepwater Horizon spill (National Response Team 1996 and 2001). The analysis of spray drift (<0.5 nautical miles) under an unlikely cross wind demonstrates that the exclusion zones (2-3 nautical miles) were protective for human exposures from spray drift to both the public and clean-up workers.

EPA Regions 4 and 6 are responsible for the waters of the Northern Gulf of Mexico. The Regional Response Teams (RRT's) in these Regions established dispersant use policies. The protocols developed by the RRT's were designed to be protective of the public, cleanup workers, and key environmental organisms (National Response Team, 1996 and 2001). The conditions under which dispersants could be applied were reported as:

- More than 3 nautical miles from shoreline
- More than 30 feet of water depth
- More than 2 nautical miles from any vessels
- More than 3 nautical miles from observed birds, sea turtles, or sea mammals

Additionally, each dispersant aircraft was accompanied by a spotter aircraft to: 1) spot oil and guide the dispersant aircraft to the oil, and 2) to enforce the exclusion zones for dispersant application that were established. While the exclusion zone from aerial spraying to the shoreline was 3 n.m., over 90% of aerial dispersant application took place over 10 n.m. from shore (Houma ICP Aerial Dispersant Group, 2010).

Further demonstration that exposure potential to sprayed dispersant was negligible are the results of the air sampling performed by King and Gibbins (2011) on response workers on vessels and the shoreline. King and Gibbons, 2011, reported that sampling was performed during the dispersant spraying activities with full-shift air sampling using National Institute for Occupational Safety and Health validated sampling and analytical methods.

- Throughout the evaluations, results for all airborne chemicals sampled were either non-detectible or well below established Occupational Exposure Limits.

In addition to quantitative exposure sampling, work practices were assessed qualitatively to identify potential hazardous exposures (King and Gibbons, 2011).

- Personal Protective Equipment was found to be matched to the level of expected or potential dermal exposure at the many sites where observations took place.
- Worker observations were carried out on beaches in 4 states where cleanup was occurring. There was no evidence of exposure to dispersants.
- Review of infirmary logs did not reveal any unrecognized or unreported occupational illness.

There were several reports from vessels that aerial spraying had taken place in their vicinity (Houma ICP Aerial Dispersant Group, 2010).

- All of these reports were investigated and the vessel positions were compared with the location of aerial spraying.
- All aerial spraying was recorded and documented with Global Positioning Systems (GPS). There was no evidence that vessels had been sprayed in any of the reports based upon GPS coordinates of the vessels, spray aircraft, and were further confirmed by reports from spotter plane records (Houma ICP Aerial Dispersant Group, 2010).
- In all cases aircraft spraying took place beyond the established exclusion zones.

CONCLUSIONS

This paper examined aerial application of oil dispersant use during the Deepwater Horizon oil spill response in the Gulf of Mexico during 2010. This analysis has examined aerial dispersant application with a Lockheed C-130, the platform for the largest volume of dispersant applied at the water surface, under the extremes of the range of wind conditions in which dispersant application was expected. The results determined that in the unlikely event that dispersant application was undertaken with the aircraft experiencing a cross-wind ranging up to 35 knots, dispersant spray would not exceed a drift distance beyond 0.5 n.m.

The procedures that were established by the Region IV and VI RRT’s for dispersant application was 2 n.m. for vessels and 3 n.m. for shorelines and marine mammals. Given the findings of the spray analysis, these exclusion zones were protective for both spill response workers and the public. This was confirmed by a health hazard evaluation that examined both vessel and shoreline spill cleanup workers. This study found no instances where dispersant constituents measures exceeded occupational exposure limits.

Dispersants are applied to surface oil on water in very low amounts. At a diluted depth of 1 meter in the water column, dispersants would be present at about 5 ppm. The dispersants and oil associated with them would continue to dilute very rapidly. This was confirmed by an EPA analysis of surface and subsurface waters during 2010. That study found no samples containing the dispersant constituent Dioctyl Sodium Sulfosuccinate, at concentrations exceeding the minimum detection limit of 20ug/L.

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REFERENCES

AGDISP V 8.28. Development Platform for US Forest Service.

Dispersant Use Approvals in the United States. Fact Sheet No. 5, Oil Spill Prevention. Oil Spill Prevention.org, American Petroleum Institute.

Ebert, T.A., Downer, R., Clark, J.R., Huber, C.A. 2008. Summary of studies of COREXIT dispersant droplet impact behavior into oil slicks and dispersant droplet evaporation. In: International Oil Spill Conference Proceedings: 2008(1):797-800.

Houma ICP Aerial Dispersant Group. 2010. After Action Report, Deepwater Horizon MC 252 Aerial Dispersant Response, December 31, 2010.

M. Johnson, D.L. Schroeder, L. B. Zintek, C.R. Schupp, M.G. Kosempa, A.M. Zachary, G.C. Schupp, and D. J. Wesolowski.2012. Journal of Chromatography A. 1231: 46-51.

King, B.S. and Gibbins, J.D. 2011. Health hazard evaluation of deepwater horizon response workers. Health Hazard Evaluation Report HETA 2010-0115 & 2010-0129-3138, August 2011.

Nalco. 2014. COREXIT® Ingredients. http://www.nalcoesllc.com/nes/1602.htm. Last accessed 4-13-2016.

Oil Spill Response Field Manual. 2014. ExxonMobil Research and Engineering Company.

Region IV Regional Response Team Ocean and Coastal Waters Dispersant Use Policy, National Response Team, 1996.

Regional Response Team – 6 FOSC Dispersant Pre-approval Guidelines and Checklist, National Response Team, 2001.

Reynolds, B. 2012. Characterization of Dynamic Aviation BE-90A King Air(s) and International Air Response (IAR) C-130A. Leading Edge Associates.