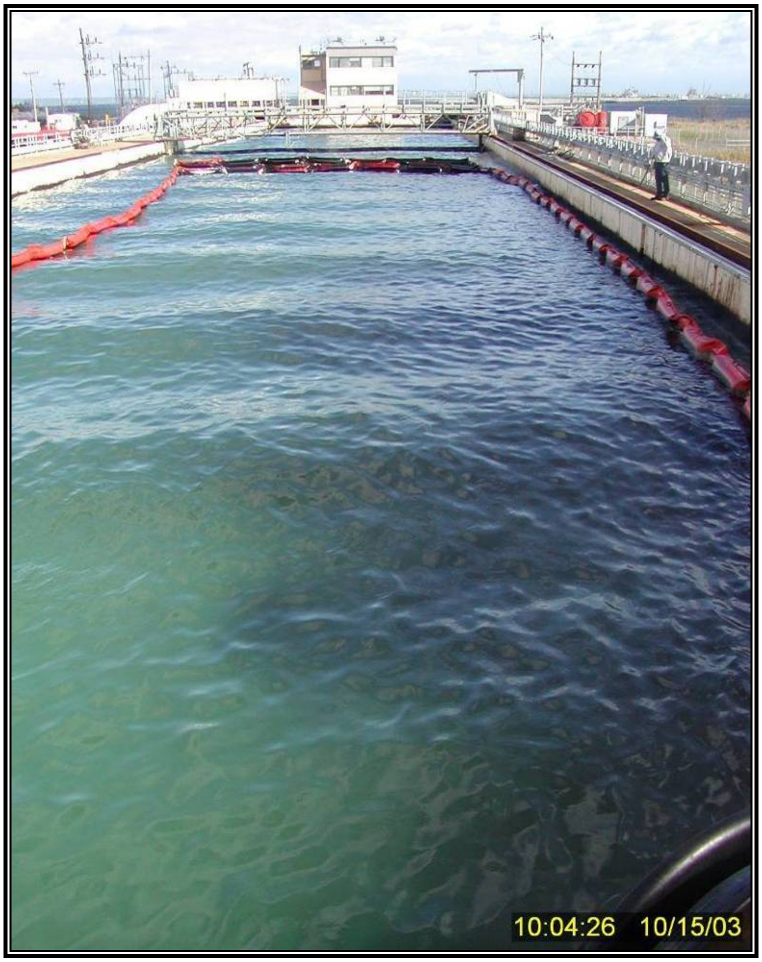
Field Notes and Critical Observations from the OHMSETT Heavy Oil Dispersant Trials

October 13-16, 2003



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Draft Report – October 29, 2003
Final Report – October 2, 2006

Regional Citizens' Advisory Council

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The opinions expressed in this commissioned report are not necessarily those of PWSRCAC

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Introduction

This report contains the transcriptions of tape-recorded notes and observations completed by Dr. James Payne during a PWS RCAC-sponsored field audit of the 13-16 October 2003 heavy fuel oil dispersant tests completed by SL Ross and Alun Lewis Consultancy at the MMS OHMSETT facilities in Leonardo, New Jersey. The draft report delivered to PWS RCAC in October 2003 contained initial observations only and figures were supplied as separate files on compact disk (CD). This final report contains all the time/date-stamped figures referenced in the earlier report (compiled in Appendix A in the order called out in the text) along with additional data from SL Ross that were not available at the time the original report was prepared.

The objectives of the tests were to correlate the OHMSETT experiments with at-sea trials of dispersant effectiveness on heavy fuel oils completed in the UK in June 2003 (Colcomb et al., 2005) and obtain additional data on defining the actual limiting viscosity of oil for dispersant use. In addition, the tests were designed to allow correlation of two semi-quantitative methods of monitoring dispersant effectiveness (in-situ fluorescence with USCG SMART and UK Protocols) and direct measurement of residual nondispersed oil on the water surface at the end of each test. Samples of the fuel oils and dispersants were also made available to the U.S. EPA and Environment Canada for independent smaller-scale laboratory tests to see if the results from the EPA's baffled-flask and Environment Canada's swirling-flask tests could be correlated with each other and the data from the larger-scale studies. Additional details on the experimental program can be found in the 1 October 2003 Operating Plan prepared by the project investigators, which is reproduced in its entirety with this report as Appendix B.

This report relies heavily on digital photographic documentation of each day's test activities. A compact disk containing all the photographic data for each day was provided to PWS RCAC with the draft report, and references to individual photographic filenames (in addition to figure numbers as used in Appendix A) are called out throughout the text. It is suggested that this report be printed, and then used to review the cited photographic records on a computer monitor so that specific photographs can be enlarged as necessary to reveal the details discussed in the text (and not always apparent at the scale and compressed resolution of the figures contained in

Appendix A). In addition to Dr. Payne's original tape-recorded observations and photo-documentation, this final report also compares his evaluations with observations and findings from the final reports on the wave-tank experiments (Trudel et al., 2005; SL Ross et al., 2005). Detailed comparisons of the results from the wave-tank studies with the at-sea trials and the parallel laboratory studies with these same oils and dispersants completed by the U.S. EPA and ExxonMobil Research and Engineering (Clark et al., 2005), are outside the scope of this project; however, a summary of the results presented in Trudel et al. (2005) and SL Ross et al. (2005) is provided. Also, an Acrobat PDF file of SL Ross et al. (2005) was forwarded to the PWS RCAC with this report to facilitate additional comparisons and review. The SL Ross report is also available for downloading at http://www.mms.gov/tarprojects/477.htm. Although invited to collaborate in the laboratory-scale studies, Environment Canada ultimately did not participate in the project.

The observations and findings contained in this report are those of the author and do not necessarily reflect those of the PWS RCAC, Alun Lewis Consultancy, SL Ross, or MMS/OHMSETT. Any errors or omissions are strictly the responsibility of the author.

Description of the OHMSETT Facilities and Overview of the Experimental Protocol

The Oil and Hazardous Materials Simulated Environmental Test Tank (OHMSETT) is 667 feet long, 65 feet wide, and 11 feet deep. Water depth is usually around 8 feet. The tank is oriented in a north-south direction with a wave generator at the southern end. The tank is spanned by three bridges mounted on rail-road wheels. One bridge is placed near the southern end of the tank to secure that end of the oil containment boom used in the experiments, the middle (movable) bridge is used for oil and dispersant applications and observations during each test, and the northern-most bridge supports a permanent boom/curtain that can be raised and lowered to sweep (herd) residual surface oil out of the test area to clean the tank between tests. There are also three underwater windows for viewing dispersed oil behavior along the western tank wall. These are equally spaced along the length of the tank to allow observations at the southern end (closest to the wave generator), the central portion of the tank (roughly in the center of the test area), and the northern end (close to the primary and secondary containment booms).

Briefly, the experimental protocol for each test proceeded as follows (see Appendix B for more details):

1. A large rectangle of containment boom is secured in the tank between the stationary northern and southern bridges.
2. The movable bridge (containing the desired test oil and dispersant) is positioned over the northern end of the rectangular test area.
3. The wave generator is turned on and sufficient time (usually 4-5 minutes) is allowed for the desired sea state to develop.
4. All data acquisition and video recording equipment are turned on.
5. Background fluorescence measurements are completed.
6. The bridge is accelerated to ~0.5 knots toward the southern end of the tank.

7. When the bridge is approximately in the center of the rectangular test area, the oil is gently discharged from a manifold system along the leading (southern) edge of the bridge onto the water surface over a 20 meter travel distance.
8. When the dispersant spray bar on the trailing (northern) edge of the bridge is approximately 1 meter from the surface oil, the dispersant spray is turned on and dispersant is sprayed onto the oil until the spray bar is approximately 1 meter past the end of the test slick. With this configuration, the oil is only on the water surface for 8-10 seconds before it is initially treated by the dispersant spray.
9. The bridge is then moved quickly (at 1 knot) over the slick to allow observations and measurements of the oil behavior immediately after treatment.
10. After additional time has passed, the bridge is then moved slowly (0.25 knots) over the slick at approximately 2 to 3 minutes, 4 to 9 minutes, and 11 to 19 minutes with fluorometer pumps and other in situ equipment positioned in the water so they travel through the center of any visible dispersed oil cloud.
11. Fluorometer readings are continuously recorded and grab water samples are collected from the fluorometer effluent for additional chemical analyses.
12. The quantities of oil discharged and dispersant applied are measured and recorded.
13. After 30-35 minutes the wave generator is stopped and the water surface is allowed to calm.
14. Any remaining surface oil is herded with fire monitors (taking care to spray the water and not the oil) to the downwind end of the containment boom for vacuum recovery and volumetric/water content measurements.

Summary of Dispersant Trials Observations and Characteristics of the Three Oils Tested

Table 1 summarizes the OHMSETT dispersant trials observed by Dr. Payne over the four-day period and includes additional summary data provided by Trudel et al., (2005) and SL Ross et al. (2005). Detail narratives describing each test are presented below by day and Test Number. All of the figure call-outs in the text are hyperlinked to the appropriate figure in Appendix A. To move directly to the figure (for quick and easy reference), place the mouse cursor over the figure call-out in the text and hold down the Ctrl button while “left-clicking” the mouse. The screen will move to the selected figure.

Table 1 is purposefully placed at the beginning of the report (next page) for easy reference back to experimental details and summary observations as the reader progresses through the text. Like the figure call-outs, the table call-outs are also hyperlinked to the appropriate table (follow the instructions above to move to the table). Although Table 1 gives away the “punch line” at the beginning of the report, the interested reader is strongly encouraged to read the detailed narrative for each test and examine the referenced figures, which contain significant details about the testing protocols and results.

Three separate intermediate fuel oils (IFO 120, 180, and 380) with significantly different viscosities were utilized for the tests observed by Dr. Payne in October 2003, and Table 2 lists the relevant rheological properties as reported by SL Ross et al. (2005). Most of the dispersant trials during the second week of testing (when these observations were documented) were

Table 1 Summary of OHMSETT Dispersant Trials Observed – October 13-16, 2003.

Test No.	Date	Start Time	Oil	Dispersant	Wave Energy (cpm)[1]	Measured DOR[1]	% Oil Dispersed (Or Lost)[2]	Comments
10	10/13/03	0950	IFO 180	none	32.6	0	26	Intermediate energy control test with no dispersant. No dispersion observed by JRP and median visual ranking of 1 by Trudel et al., 2005.[3,4]
11	10/13/03	1128	IFO 180	Agma DR 379	28.7	1:105	24	Low energy. No dispersion observed by JRP. Median visual ranking of 1 by Trudel et al., 2005.[3]
12	10/13/03	1404	IFO 180	Agma DR 379	33.0	1:148	17	Intermediate energy. Median visual ranking of 2 by Trudel et al., 2005.[3] Delayed and only moderate dispersion (~10-15 min after treatment) observed by JRP. Localized dispersion enhanced by turbulence due to northeast corner of boom interacting with passing waves, and significant dispersed oil droplet resurfacing noted 25-35 minutes after cessation of turbulence.
13	10/14/03	0916	IFO 180	Superdispersant SD25	29.2	1:129	21	Low energy. Median visual ranking of 1 by Trudel et al., 2005.[3] No dispersion anticipated (based on at-sea trials) or observed. No dispersion noted by JRP, no oil in secondary containment boom, excellent water clarity at end of test.
14	10/14/03	1113	IFO 180	Corexit 9500	28.8	1:101	21	Low energy. Median visual ranking of 1 by Trudel et al., 2005.[3] No dispersion noted by JRP, no oil in secondary containment boom, excellent water clarity at end of test. Compare to Test No. 19 at higher DOR.
15	10/14/03	1345	IFO 180	Superdispersant SD25	33.3	1:106	45	Intermediate energy. Median visual ranking of 3.5 by Trudel et al., 2005.[3] Very extensive dispersion observed by JRP after 2-4 minutes. Eventually most of the water column in the middle and northern part of the tank was completely black. Only very minimal dispersed oil droplet re-surfacing at the end of the test.
16	10/14/03	1518	IFO 180	Corexit 9500	33.4	1:106	84	Intermediate energy. Median visual ranking of 4 by Trudel et al., 2005.[3] Extensive dispersion observed by JRP after 5-7 minutes, and eventually most of the water column in the middle and northern part of the tank was completely black. Only very minimal dispersed oil droplet re-surfacing at the end of the test and after 15 hours of calm conditions over night.
17	10/15/03	0947	IFO 120	Corexit 9500	29.1	1:63	39	Lower viscosity oil test. Low energy but strong cross winds blew oil to eastern edge of containment boom. JRP noted additional dispersion imparted by turbulence along boom. Not scored numerically by Trudel et al., 2005 or SL Ross et al., 2005, but not considered particularly successful.

18	10/15/03	1218	IFO 120	Corexit 9500	32.9	1:106	66	Lower viscosity oil test. Intermediate energy and strong westerly cross winds (gusts to 50 mph) blew oil to eastern edge of containment boom. JRP noted significant dispersion in the center of the tank and additional dispersion imparted by turbulence along boom. Twenty-four minutes into the test, the boom pulled free of mooring at southwest corner of tank and collapsed against eastern side of the tank wall. Not scored visually by Trudel et al., 2005 or SL Ross et al., 2005. Not all of the nondispersed surface oil was recovered at the end of the test because of the collapsed boom.
19	10/16/03	0938	IFO 180	Corexit 9500	29.1	1:63	36	Intermediate viscosity oil test at low energy but higher DOR target (1:25). Median visual ranking of 1 by Trudel et al., 2005.[3] JRP suspects higher measured dispersion (36%) due to turbulence from waves and oil interacting with containment boom in northeast corner and along entire length of tank. At the higher DOR, the oil was much more subject to anomalous dispersion during collection. Compare to Test No. 14 at lower DOR where the oil stayed more in the center of the tank.
20	10/16/03	1158	IFO 380	Superdispersant SD25	33.5	1:104	53	Higher viscosity oil test. Median visual ranking of 3.5 by Trudel et al., 2005.[3] Very significant dispersion observed by JRP early in run with some residual nondispersed oil accumulating along eastern containment boom. Eventually much of this oil was also dispersed.

Notes:

1. **Measured data from Trudel et al. (2005) and SL Ross et al. (2005).**
2. **Direct measurement of remaining surface oil collected at end of the test subtracted from original volume of oil released and expressed as a percent (from Trudel et al., 2005 and SL Ross et al., 2005). This value would include oil lost to evaporation (minimal for IFOs), adhering to the boom, and any oil that may have splashed over the primary (and secondary) containment booms during a test. Fortunately, the addition of a secondary containment boom at the north (down-wave) end of the tank allowed the capture of most oil that was lost to splash-over, so this source of oil loss was accounted for during the tests observed by J.R. Payne.**
3. **See Figure 6 in Appendix A for definitions of numerical rankings and a blank score sheet used by trained observes during the tests.**
4. **Range of measured air and water temperatures during tests (13-21^{o} C) and (15-18^{o} C), respectively (see SL Ross et al., 2005 for more details).**

Table 2 **Rheological Properties of the Intermediate Fuel Oils Used During the October 2003 OHMSETT Tests (from SL Ross 2005)**

Oil Type	Density (g/mL @ 20° C)	Viscosity, Pa.s (centipoise cP)			
		@ 16° C		@ 50° C	
		@ 10 s^{-1}	@ 100 s^{-1}	@ 10 s^{-1}	@ 100 s^{-1}
IFO 380	0.983	7,100	n.a.	314	324
IFO 180	0.970	2,075	1,925	134	146
IFO 120	n.a.	1,145	1,145	87.5	87.5

n.a. = not available

completed with the intermediate viscosity IFO 180, although two runs (Test Nos. 17 and 18) were completed with the lower viscosity IFO 120, and one run (Test No. 20) was completed with the higher viscosity IFO 380. Test Nos. 1 through 9 (with IFO 380) were completed the week before because only limited chemically enhanced dispersion was expected (based on the at sea trials), and as will be clearly shown in this report, it is important to plan and arrange the tests from the least to the most expected dispersion to keep the wave tank as clean as possible for the majority of the experiments.

Tape Notes from October 13, 2003

Initial tests were undertaken using intermediate fuel oil (IFO) 180. This series of experiments will be undertaken with a variety of observation methods (see Appendix B). These include visual observations from the surface (including videotape and still photography), UV fluorescence (from submersible pumps providing continuous flowing samples from 1- and 2-meter depths plumbed directly into two separate Turner 10 AU fluorometers (Figure 1 – photo file P1010018) and a separate Wetlabs FL-3 in situ fluorometer (Figure 2 and Figure 3 – photo files P1010036 and P1010037), which sent a signal directly back to a computer readout), and in situ oil droplet size distributions measured with a LISST-100 in situ laser scattering and transmission device (particle size analyzer) (Figure 4 and Figure 5 – photo files P1010029 and P1010030). The LISST-100 particle size analyzer is reportedly good for measuring mean-volume particle diameters from 10-200 micrometers (µm). The Wetlabs FL-3 in situ fluorometer has three different channels. For the chlorophyll channel, the excitation wavelength is 470 nm and the emission wavelength is 695 nm. For the fluorescein calibration channel the excitation wavelength is 470 nm and the emission wavelength is 530 nm. For the CDOM (colored dissolved organic matter) channel the excitation wavelength is 390 nm with an emission wavelength at 460 nm. The visual observations of surface oil behavior were completed by three independent and trained observers (see Appendix B). They each scored the dispersant effectiveness on score sheets like the one shown in Figure 6. These data were then compiled by the project investigators at the end of each day, and the results were used to numerically score the test effectiveness as reported by Trudel et al. (2005) and shown in Table 1.

The Turner 10 AU fluorometers were calibrated with a nominal 100 ppm solution/suspension of the IFO 180 plus Corexit 9500 prepared from a premix of the oil and dispersant mixed directly into a 20 liter aliquot of the seawater from the tank. (The calibration solution was prepared volumetrically, and serial dilutions were also completed to generate 50, 25, and 12.5 ppm solutions for additional calibration of the Turner 10 AU fluorometers). For the sake of completeness and inter-comparability, the 100 ppm calibration solution was also used to calibrate the Wetlabs FL-3 in situ fluorometer and the LISST particle size analyzer used by Chris Fuller from Texas A&M University (Figure 7 – photo file P1010021).

The Turner 10 AU fluorometers were first blanked with seawater from the tank and then calibrated with the dispersed oil and dispersant in seawater from the tank.

The water temperature for these tests was 64 degrees Fahrenheit, and the wind was blowing from the north at ~ 3-6 knots.

Most of the effort until approximately 0930 hours on the morning of 13 October 2003 was spent in removing the last remnants of IFO 380 fuel oil from the tank from the previous week's experiments, setting up equipment, and calibrating instrumentation as noted above (see Figure 8 through Figure 12 – photo-files P1010001, P1010004, P1010011, P1010012 and P1010007).

Test No. 10 – IFO 180 control (no dispersant added), intermediate (33 cpm) energy waves

At 0950 hours, an initial control experiment (Run No. 10) with IFO 180 was initiated. This was a control test with no dispersant added and intermediate energy waves generated at a nominal wave generator paddle frequency of 33 cycles per minute (cpm). Low energy waves are generated at 30 cpm and high energy waves (not used in any of these tests) are generated at 35 cpm. See Figure 13 through Figure 17 (photo files P1010039, 41, 46, 49, and 50) for the start-up and initial 60 seconds of the test. Figure 18 (photo-file P1010051) shows the in situ LISST and Wetlabs FL-3 instrument package beneath the water surface approximately 10 minutes into the experiment. There was no evidence of any oil dispersion; however, within about 20 minutes most of the oil had been blown by the northerly wind toward the south end of the experimental zone generated by the containment boom. Interestingly, under these wind conditions, the oil drifted against the prevailing wave train. See Figure 19 (photo file P1010054 – looking towards the north) and Figure 20 (photo file P1010056 – looking towards the south). There was absolutely no evidence of any oil splashing over the containment boom, although this experiment was a little different from more traditional runs because the oil was driven by the wind not the waves as is usually the case. Figure 21 and Figure 22 (photo files P1010061 and P1010067) show the oil within the containment boom at the south end of the tank just before and after the wave generator was turned off. After the termination of the test, the movable bridge was relocated to the south end of the tank, and the high-pressure water hoses (fire monitors) were used to drive the surface oil to the north end of the tank for collection and quantitative measurement of nondispersed recovered oil. During this operation, extreme care was taken to direct the water from the fire monitors onto the water next to the surface oil (not the oil itself) to herd the oil in the desired direction while keeping the amount of oil entrainment into the water column to an absolute minimum. Even with this care, however, approximately 26% of the oil was not recovered (see Table 1 and further discussion below).

Test No. 11 – IFO 180 plus AGMA DR 379 (nominal DOR 1:50), low (30 cpm) energy waves

The test oil was again IFO 180, but in this case the oil was sprayed with one of the lesser effective dispersants (AGMA DR 379 – based on the at sea trials) with low-energy (nominal 30 cpm) wave turbulence. Because of the results from the at-sea trials, very little dispersion was anticipated for this test. This test was initiated 1128 hours. Figure 23 through Figure 27 (photo files PA130076, 78, 79, 80, and 81) show the oil being gently laid down on the tank's water surface and initial spray applications with the dispersant at a targeted dispersant-to-oil ratio (DOR) of 1:50. As shown in Table 1, the actual DOR was closer to 1:100 after correcting for the uneven distribution of the viscous oil on the water surface and the fact that much of the dispersant was applied directly to the water. In Figure 26 (photo file PA130080), a trace of dispersion can be observed from turbulence introduced by the tubing from the submersible pumps providing samples to the Turner fluorometers. This was the only evidence of any dispersion during the first 60 seconds of the test (Figure 27 and Figure 28 – photo files PA130082 and 83), and it clearly was an artifact of the tubing being dragged through the freshly treated oil. I estimate that less than 1 percent of the oil was affected by dragging the fluorometer tubing through the treated slick. Figure 29 (photo file PA130086) shows the oil spreading out on the water surface during the first two to three minutes of the test. The photographs were taken from the bridge looking to the north in the down-wave direction. Figure 30, Figure 31, and Figure 32 (photo files PA130087, 89, and 90) show close-ups of the oil looking directly down from the bridge after approximately four minutes. There was little or no evidence of successful dispersion into the water column. In this test, as in the previous test (No. 10), the wind was blowing out of the north, so the wind was more of a controlling factor on the oil movement than the waves. As a result, the nondispersed oil again ended up in the south end of the test zone (towards the wave generator) inside the containment boom. Figure 33 and Figure 34 (photo files PA130096 and 98) show the oil collecting in the south-east corner of the experimental enclosure. As in the previous test, there was no evidence of any nondispersed oil splashing over or escaping from the experimental zone under these light wave-turbulence conditions. Figure 35 (photo file PA130108) shows the oil in the south east corner of the test zone after the wave turbulence was discontinued. The oil outside the boom in Figure 35 and Figure 36 (photo files PA130108 and 109) was residual IFO 380 fuel oil from the previous week's testing that had accumulated around the paddles at the south end of the tank. The IFO 380 oil could be distinguished from the IFO 180 used in Test No. 11 because it was clearly more viscous and had different flow properties. I personally did not observed any oil splashing out of the experimental zone during the test.

Figure 37 through Figure 40 (photo files PA130110, 112, 114, and 116) show the collection of the nondispersed IFO 180 oil at the end of the experiment. Note that the water spray used to herd the oil was not sprayed on oil directly but instead on the water surface 10-15 feet from the oil to aid in pushing it to the corner for subsequent vacuum recovery. After the oil was collected (Figure 39 and Figure 40 – photo files PA130114 and 116), it is allowed to stand sealed in 55 gal. drums until it can be decanted, the volume and density measured, and the water content determined. Those data were provided in the IOSC conference proceedings paper (Trudel et al., 2005) and the SL Ross final report (SL Ross et al., 2005), and they are summarized in Table 1. From those data (from Test Numbers 10 and 11 with little or no dispersion noted), it is clear that perhaps as much as 20-25% of the oil added is lost (not recovered) due to adhesion to the boom, evaporation (not really much of a factor with heavier oils), or inefficiencies in collection. Test numbers 10 and 11 serve as controls to demonstrate the recovery efficiency of the experimental protocol under conditions where little or no dispersion occurs. In this context, however, it is important to stress that not too much emphasis should be placed on trying to differentiate between 17 vs. 20 vs. 30 percent dispersion values in Table 1). As will be demonstrated later (e.g., with Test Nos. 15, 16, 18, and 20), when effective chemical dispersion occurs, it is very obvious by visual and numerical scoring, and the measured percent dispersed values (obtained from residual surface oil collected at the end of the test) are significantly different from the nondispersed controls or results obtained from the poorer performing dispersants and lower energy conditions.

Test No. 12 – IFO 180 plus AGMA DR 379 (nominal DOR 1:50), intermediate (33 cpm) energy waves

The wave generator was turned on at 1355 hours. The AGMA dispersant will again be applied onto the IFO 180 fuel oil at a nominal dispersant/oil ratio (DOR) of 1:50 (measured DOR was 1:150 see Table 1). In this test, however, the wave energy turbulence will be increased to 33 cpm. At this setting, occasional whitecaps (ranging in size from 2-6 inches) can be observed sporadically throughout the test area. At any given time, however, no more than 2 or 3 such whitecaps are present within the test zone, and generally it is just a rogue wave that gently crests and rolls for 5-10 feet before the white water disappears.

The test was initiated at 1404-1405 hours (Figure 41 – photo file PA130128). For the first four minutes after the dispersant was added there was no evidence of any dispersion of the oil into the water column (Figure 42 and Figure 43 – photo files PA130133 and 135). Then two breaking waves occurred in the middle of the treated slick, and on that part of the slick, it was possible to see that a small amount of oil (from just that area) was dispersed as a black plume below the surface slick into the water to the depth of maybe 1-2 feet (Figure 44 – photo file PA130137). The total amount of oil dispersed was not very impressive, and a majority of the oil was observed to be driven by the waves (which were now dominant over the wind) towards the north end of the test enclosure (Figure 45 and Figure 46 – photo files PA130147 and 149). While all the surface oil was affected by the wave-train and driven to the north, the dispersed oil cloud did not move with the waves towards the north end of the tank and instead spread laterally as shown in Figure 47, Figure 48, and Figure 49 (photo files PA130150, 152, and 154). As shown by the figures the wave turbulence was not quite at the breaking wave stage, so the extent of dispersion was somewhat limited. After approximately 17 minutes, small dispersed oil droplets could be observed through the underwater view ports, but they were too small to photograph successfully (Figure 50 – photo file PA130155). Even though the dispersant effectiveness was pretty poor, there was sufficient oil in the water to obscure a clear view of the containment boom, which was clearly visible through the underwater view port before the tests were undertaken Figure 12 (photo file P1010007). There was definitely something in the water column; however, it was impossible to tell if it was from this last experiment or if it was the result of all the activities that had been completed during the day up to this point. With 20:20 hindsight, this underwater view port should have been checked and photographed before this experiment (No. 12) was initiated. In this regard, it also would have been very helpful to see what particle size distributions were measured with the LISST instrumentation; however, those data were never provided by Texas A&M University (Chris Fuller) to OHMSETT or the National Academy of Sciences/National

Research Council for their review of current dispersant research issues (NRC 2005) despite repeated requests by both MMS/OHMSETT/SL Ross personnel and members of the NRC review committee.

The double boom (secondary) containment system at the down-wave end of the tank appeared to be working relatively well at capturing the limited amount of oil that did splash over the boom at the north end of the primary containment zone. The containment boom was configured such that the oil was laid down and dispersant applied within the primary experimental zone with a secondary containment zone like an “end zone” on a football field at the north end of the tank. It should be remembered that the wave train moves from the south to the north end of the tank (from the right to the left in Figure 49, Figure 51, and Figure 52). The secondary "end zone" was intended to capture oil that splashed out of the experimental zone of the tank to improve the collection efficiency and quantification of nondispersed oil at the termination of each experiment. Figure 51 (photo file PA130160) shows the wave-induced strain and potential splash-over of surface oil into the secondary containment zone with a small standing-wave crest breaking within the secondary containment zone itself. This photograph also illustrates the small magnitude of the waves that was sufficient to enhance dispersion (it doesn't take much). In this regard, however, it is also highly probable that there is additional near-surface turbulence introduced by the waves passing under the boom(s) (particularly at the north end of the tank), and this probably enhances dispersion (entrainment) of any oil that migrates to this region. The other thing that is apparent in Figure 51 and Figure 52 (photo files PA130160 and 161 taken about 24-5 minutes into the test) is the extent of dispersed oil which migrates under the boom and diffuses both longitudinally and laterally in the water column under and adjacent to the test area. This is oil that was successfully dispersed into the water column, but it makes it difficult to see in the photographs just how effective the primary boom was at holding the surface nondispersed oil in the test area because the water column under the secondary "end zone" containment boom is also very dark. This is particularly apparent in Figure 52 (photo file PA130161); however, observation of the water surface clearly shows the difference in surface texture where the smoother surface oil is contained within the primary experimental zone on the right hand side of the boom compared to the more choppy water surface between the primary boom and the secondary containment boom in the center of the photograph. Also, note that there is absolutely no surface oil outside of the secondary containment zone on the left side of the photograph. Figure 53 (photo file PA130163) shows the discoloration of the water column between the containment boom and the western tank wall due to lateral migration/diffusion of subsurface dispersed oil droplets at the north end of the experimental enclosure.

At the conclusion of each experiment all the oil in both the primary experimental zone and the secondary containment zone was herded/collected and combined as nondispersed oil (see Figure 54 and Figure 55 – photo files PA130172 and 174). Note the relative difference in the amount of oil in the primary containment zone to the left and the secondary containment zone to the right in Figure 55 (photo file PA130174). I estimate that the oil in the secondary containment is less than 5 percent of the oil in the primary containment zone; however, there is also a fair amount of oil between the boom and the tank wall (Figure 55) and further to the north of the secondary containment boom (Figure 56 – photo file PA130180). This oil could have been splashed out of the test enclosure (although I didn’t observe this during the test – also see Figure 52 which shows little or no oil outside the secondary containment boom near the end of the test), or it could have been from an earlier test. I consider this latter possibility to be less likely, as the entire tank (inside and outside of the experimental boom) is usually swept as clean as possible before each test. Another possibility is that it could be from larger than normal-sized drops of dispersant-treated oil that is entrained under the boom by the increased turbulence regime in this region (see Figure 51). The oil in these larger droplets would be subject to more rapid resurfacing after turbulence is discontinued. Figure 56 and Figure 57 were taken approximately 20 minutes after the waves were turned off, and the surface oil in these photographs has a distinctly different appearance than that observed for smaller, dispersed-oil droplets that resurfaced after a longer period of quiescence (see Figure 58 through Figure 60 as discussed further below).

As noted above, the oil that was within the secondary containment boom is included in the nondispersed oil calculation, although it is not quantified separately. The oil outside the containment booms (shown in Figure 55 and Figure 56) is not included in any calculations, although in this test over 83% of the non-dispersed oil was recovered and accounted for yielding a dispersed oil efficiency of 17% (see Table 1). Including the oil trapped within the secondary containment boom clearly minimizes the amount of oil that had escaped from the experimental system in earlier OHMSETT tests. In future tests, however, it might be prudent to collect the oil in the primary test zone and the secondary containment zone separately such that the percentage of nondispersed oil which actually did splash over (escape from) the primary boom could be calculated. Likewise, collection of oil outside the containment zone (such as that shown in Figure 55 and Figure 56) might also improve on the overall mass balance and provide an estimate on the amount of dispersed oil subject to resurfacing (more on this below). In test No. 12, the wind was not as strong as it was in the morning, so the oil transport was driven primarily by the waves and not the wind. Therefore, the nondispersed oil did concentrate as expected in a band at the north end of the experimental zone adjacent to the secondary containment zone. Once there, however, it may have been subjected to additional (and anomalous) turbulence/shear due to the waves and surface oil interacting with the containment boom(s), and this may have contributed to enhanced dispersion.

The dispersed oil droplets which are not subject to transport by the wind remained more in the center and along the edges of the tank as shown in Figure 47, Figure 48, and Figure 49. At 1435 hours the waves were turned off, and at 1454 hrs (18-20 minutes later) there was a fair amount of previously dispersed oil that had resurfaced outside the boom along and at the north end of the tank (Figure 55 and Figure 56). As noted above, I believe that much of this oil may have come from larger oil droplets entrained into the water column by the enhanced turbulence regime introduced by the waves interacting with the booms at the north end of the tank. Larger droplets will resurface more rapidly (NRC 1989, 2005), and this may explain the significant oil slicks observed outside the north end of the experimental enclosure relatively soon after the test was terminated. Elsewhere, however, the water surface remained fairly free of resurfacing oil, and it was only after another 15-20 minutes of calm conditions that dispersed oil droplets began to appear. Presumably, these differential rates of droplet resurfacing reflect different median droplet size distributions throughout the tank, and again the data from the LISST particle size analyzer would have been very useful.

At 1500 hours (25 minutes after the wave turbulence was stopped) there was still a lot of colloidal and particulate material suspended in the water column that could be viewed from the underwater view ports. Whether or not it was dispersed oil or resuspended sediments from the bottom (or combination of both) was impossible to state. Nevertheless, the water was definitely much more turbid than it was at the beginning of the test (unfortunately, no photographs are available). At 1508 hours there was a lot of oil resurfacing outside the boom along the edge of the tank. Based on its appearance as small finite droplets on the water surface, I believe it is truly dispersed oil that has now resurfaced rather than bulk quantities of oil that were washed from the experimental zone during the test. Figure 58, Figure 59, and Figure 60 (photo files PA130189, 191, and 192) show this resurfaced oil between the western tank wall and the primary containment boom. From the deck six feet above the tank, it looks like the diameter of these droplets might range from less than a millimeter to three or four millimeters across. Within a period of approximately two minutes, it appears that many of the smaller droplets are agglomerating into 1-2 cm size patches (see Figure 59). In looking at this resurfaced oil, it should be remembered that this was not considered to be a particularly successful dispersant test. That is, the low efficiency dispersant did not disperse most of the oil, and what did disperse probably generated larger size droplets. It is truly unfortunate that Texas A&M University did not release any oil droplet particle size data that were collected for these tests. Nevertheless these observations document that once the wave turbulence is turned off, there is resurfacing, although quantitatively it is impossible to say exactly how much.

These observations suggest an additional possible modification to the experimental protocol such that after a successful dispersant test and after the wave generator has been turned off, surface collections could be completed as a function of time. That is, the resurfaced oil in different regions could be collected at say, 15 minutes, 30 minutes, one-hour, and two hours after cessation of turbulence to document the amount of oil that resurfaced as a function of time. These data combined with droplet size distributions might then allow the test results to be extrapolated to open ocean conditions where most of the literature reports that oil droplets less than 50-70 micrometers (µm) are permanently dispersed (NRC 2005).

At the termination of the day’s testing activities, the wave generator was turned back on at a pulse rate of 35 rpm to drive all the oil that had not previously been collected to the north end of the tank. Fire monitors were also used to wash residual free oil from the tank walls and containment booms, and after the waves were turned off, any remaining surface oil was then driven under the curtain boom below the northern-most stationary bridge (see Figure 61 – photo file PA130186). This approach also facilitated cleaning (polishing) the tank the following morning before the next series of experiments.

Tape Notes from October 14, 2003

Test No. 13 – IFO 180 plus Superdispersant-25 (nominal DOR 1:50), low (30 cpm) energy waves

There are no specific tape notes for test No. 13, which was the initial test run on Visitor’s Day. I did not have the tape recorder with me at the time the test was initiated. This test was undertaken using IFO 180 and (based on the at sea trials) another of the poorer performing dispersants (Superdispersant-25) at the lower wave turbulence level (30 rpm). Because of the prior poor dispersant performance in the at-sea trials and the low wave energy, this test served as a pseudo-control to demonstrate the standard operating procedures for the visitors from the U.S. EPA, the U.S. Coast Guard, and Exxon/Mobile. Figure 62 through Figure 70 (photo files PA1400011, 19, 21, 23, 29, 32, 35, 38, and 40) document the time-series slick behavior from this test. The wind was blowing very lightly from the north again this morning, so most of the oil drifted with the wind rather than the low-energy waves and accumulated at the south end of the containment boom (closer to the wave generator). Figure 69 (photo file PA140038) shows the movable bridge parked over the south end of the boom, and the oil can be observed corralled in the southeast corner immediately below the tubing used for the onboard one- and two-m Turner fluorometers. There was essentially no dispersion observed, and the corralled oil was successfully collected at the termination of the test. The oil recovery data (Table 1) showed an overall recovery of 79 percent of the oil initially added to the tank (21 percent dispersed or otherwise not recovered). There was no dispersion noted, so one might have expected something closer to 100 percent recovery; however, as noted earlier, anywhere from 17-25 percent of the oil added in most of the control or poor dispersant/low energy tests is lost due to adhesion to the boom, evaporation, natural dispersion, or collection inefficiencies. Figure 70 (photo file PA140040) shows the clarity of the tank from the underwater view ports at the termination of the test. The containment boom and anchor chain weights hanging from the boom are clearly visible in both pictures. Also, with the northerly breeze blowing most of the surface oil to the south, and the lack of any significant dispersion/entrainment, there was no oil in the primary or secondary containment zones at the north end of the tank (Figure 71 -- photo file PA140043) at the end of the test.

Test No. 14 – IFO 180 plus Corexit 9500 (nominal DOR 1:50), low (30 cpm) energy waves

It's now 1130 hours, and we are approximately 18 minutes into test No. 14 (I got the tape recorder back from my briefcase inside the office building). This is the second test run today, and it is with IFO 180 treated with Corexit 9500 at a nominal dispersant to oil ratio of 1:50 and the low (30 cpm) energy wave turbulence regime. Table 1 lists the measured dispersant to oil ratio (DOR) at 1:100 because half the dispersant was observed to land on the water surface instead of the patchily distributed oil resulting in significant under dosing. Figure 72 through Figure 91 (selected photo files PA140046 through PA140105) show the complete time-series evolution of this test. In addition to the equipment that was used yesterday, the U.S. Coast Guard provided a third fluorometer to evaluate their SMART (Specialized Monitoring of Advanced Response Technologies) fluorescence protocols during today's tests. Figure 73 (photo file PA140047) shows the sampling tube at a depth of approximately 1 m, and Figure 74 (photo file PA140048) shows the fluorometer on the main deck of the experimental bridge. After the oil was laid down (Figure 75), it was immediately treated with Corexit 9500; however, there was no evidence of any chemical dispersion at the low turbulence regime used in the test (Figure 76 through Figure 80 – photo files PA140051, 56, 58, 59, and 60). This result was somewhat surprising, because in the at-sea trials under light wind conditions, the IFO 180 was successfully dispersed with Corexit 9500 at this dispersant to oil ratio (personal communication, Alun Lewis). It is believed that the lack of dispersion in this test is due to not quite enough wave energy being input into the system (the wave generator frequency was measured at 28.8 cpm instead of the desired 30 cpm (Table 1)). When just a little bit more turbulence was introduced by the fluorometer sampling tubing and electrical cables from the in situ fluorometer and LISST-100 being dragged through the slick at half a knot, it was enough to cause dispersion of just that region of the slick as shown by Figure 81 through Figure 84 (photo files PA140070, 71, 74, and 75). This was acknowledged to be an artifact by Ken Trudel and Randy Belore (of SL Ross), and the behavior was NOT scored as representing successful dispersion for this particular test. As a result, a median numerical dispersion ranking of only 1 was obtained for this test (Table 1).

Because of this observed anomaly, the fluorometer tubing and electrical cables were purposefully pulled from the tank in all future runs during the first pass of the movable bridge over the dispersant-treated slick for visual observations and videotape/still photography documentation. After the first pass, the sampling tubes and electrical cables for the in situ fluorometer and LISST-100 particle size analyzer were placed back in the tank for subsequent passes and positioned just to the side in such a way that they would not be dragged through the main portion of the experimental slick. The scientists and technicians involved in the experiments really went out of their way to avoid any artificial dispersion caused by sampling artifacts or the experimental protocols.

Figure 85 presents an enlargement of a small patch of surface and dispersed oil from the center of Figure 82 (photo file PA140071). This is a particularly good example of what dispersed oil looks like next to non dispersed oil. From the figures is obvious that the turbulence level was very low as there are no whitecaps and only a gently rolling wave pattern is observed (for example see Figure 77 -- photo file PA140056). Later on in the test, an interesting waveform developed such that there was a standing wave pattern going laterally in the tank (from east to west) as well as the longitudinal wave train from the south towards the north end of the tank (see Figure 86 (photo file PA140077). This wave pattern was unusual in that it hadn't been observed before; however, there was still not enough energy to impart a successful dispersion of the oil. The cross-channel wave pattern subsided at approximately 1135 hours (23 minutes into the test). Under these conditions the non dispersed oil was observed to collect primarily along the east side of the primary containment boom (Figure 84 and Figure 86 – photo files PA140075 and PA140077). The water clarity remained very good as viewed from the underwater view ports (Figure 87 – photo file PA140083), and there was little or no evidence of any oil splash over into the secondary containment boom (Figure 88 and Figure 89 – photo files PA140084 and 93). At the termination of the test, all the non dispersed oil was herded by the fire monitors directing water spray onto the water (NOT the oil) as shown in Figure 90 and Figure 91 (photo files PA140101 and 105). The white foamy material mixed in with the oil in this latter set of photographs is the dispersant. As shown by the data in Table 1, 79 percent of the initial oil released into the tank was recovered at the end of the test (i.e., 21 percent was lost to evaporation, natural and chemically-enhanced dispersion, adhesion to the boom, or collection inefficiencies).

Test No. 15 – IFO 180 plus Superdispersant-25 (nominal DOR 1:50), intermediate (33 cpm) energy waves

It is 1328 hours, and MMS and SL Ross personnel are preparing to undertake test No. 15 (Figure 92 – photo file PA140110), which will be with IFO 180 fuel oil plus Superdispersant-25 at a nominal dispersant to oil ratio of 1:50 and the intermediate wave-turbulence regime (at 33 cpm on the wave generator). As shown in Table 1, the actual DOR was estimated at 1:100 because of the aforementioned issue of approximately half the dispersant being sprayed directly into the water because of the patchy nature of the viscous oil before it has a chance to spread as it passes under the bridge toward the dispersant spray boom. When tested earlier this morning, this dispersant did not give effective dispersion at the lower energy regime of 29.2 cpm on the wave generator. Figure 93 (photo file PA140111) shows the clarity of the water when viewed from the northern-most underwater window before the test was initiated. The containment boom and anchor chain along the western edge of the tank are clearly visible. Figure 94 and Figure 95 (photo files PA14113 and PA140119) show the wave train established before the test was initiated. This is definitely a higher energy regime than that used for test No. 14; however, breaking waves were not common. Figure 95 (photo file PA140119 shows a typical whitecap from this setting on the wave generator. Clearly, it is not a high-energy regime. With the wave generator turned on, the oil was then gently applied to the water surface at 1345 hrs as the bridge was moved to the south (toward the wave generator) at approximately ½ knot (Figure 96 -- photo file PA140121). [It should be noted that for all the experiments undertaken with the IFO fuel oils, the wave train was always turned on before the oil was applied from the moving bridge to the water surface. This was a modification of the protocol described in Appendix B and the procedure used earlier with the Alaska North Slope crude oil tests under cold conditions when the oil and dispersant application were completed first (Belore 2003; SL Ross and MAR 2003). With those earlier tests, it was observed that the wave train took too long to develop using the older procedure, and that under certain wind conditions (from the east or west) the oil would drift to the edges of the containment boom before the sea state could be fully developed.]

Figure 97, Figure 98, and Figure 99 (Photo files PA140122, 123, and 125) show the application of the dispersant from the spray boom mounted on the north side of the movable bridge. Because of the close proximity of the oil manifold on the south side of the bridge and the dispersant spray boom on the north side, the dispersant is sprayed onto the oil almost immediately (within 8-10 seconds) after it is applied to the water surface. As a result of this short time interval, the oil has not spread out to form a continuous slick, and a lot of the dispersant misses the oil and goes directly into the water. It is also apparent from the above figures that the dispersant is not sprayed onto the oil with enough force to drive the oil into the water column (see Figure 100, which is a close up of the oil immediately under the dispersant spray pattern in Figure 98). Also note that the Turner fluorometer sampling tubing and electrical cables for the in situ fluorometer and LISST-100 particle size analyzer are off to the side (Figure 97 through Figure 99) and are not being dragged through the main portion of the treated slick.

In Test No. 15, the oil was laid down at 13:45:30 hours and the dispersant application was terminated after all the oil had passed beneath the movable bridge at ~13:46:30 hours. From the photographs, it is obvious that the oil coverage on the water surface is not 100 percent, and so a significant fraction of the dispersant actually hit the water and not the oil. Also, there was a fair amount of dispersant drift due to the wind, so not all of the dispersant actually landed on either the oil or water surface. The amount of dispersant that drifted away it is impossible to estimate. These factors will lead to under-dosing of the oil itself. To calculate the oil thickness and a more accurate dispersant to oil ratio, Ken Trudel routinely photographed the appearance of the oil slick through a view port cut into the floor of the bridge as it passed over the oil before the dispersant was applied in every test. Based on the surface area documented in the photographs, the investigators then calculate the average oil surface area vs. the water surface area. Knowing the volume of oil discharged and the surface area covered, the oil thickness can then be calculated. These data are used to ultimately yield a more accurate dispersant to oil ratio (Table 1) compared to the nominal values estimated by the volume of oil discharged and the volume of dispersant applied during the test.

Figure 101 through Figure 104 (photo files PA140128, 131, 136, and 137) show the appearance of the dispersant-treated oil in the center of the tank over the next two minute period. Quite clearly, the oil is beginning to be dispersed into the water column as it spreads out in the center of the experimental treatment zone. A large amount of the oil appears to be resident in the center portion of the tank, and it is not being affected by the wind because it is all subsurface. There's still a small but finite amount of surface oil that didn't get dispersed, however, and this can be observed accumulating against the north edge of the primary containment boom in the tank in Figure 105 and Figure 106 (photo files PA140139 and PA140140). The effect of the slightly increased turbulence due to the wave train impinging on the north end of the containment boom, and its influence on additional dispersion, can be observed in Figure 107 (photo file PA140142). Without a doubt, this does cause some additional dispersion; however, significant dispersion was also occurring with most of the oil elsewhere throughout the tank away from the booms as shown in Figure 108 and Figure 109 (photo files PA140143 and PA140145). These latter figures were taken over the next two minutes, and no more than seven minutes from the time of initial dispersant application. The effect of the dispersed oil diffusing <u>under</u> the primary containment boom is readily apparent in Figure 110 (photo file PA140146), along with the remaining dispersed oil distributed evenly throughout the tank as shown in Figure 111 through Figure 113 (photo files PA140149, 154, and 157). These photographs were taken between eight and eleven minutes after dispersant application. Figure 114 (photo file PA140161) shows the readout from the in situ fluorometer over the duration of the test. Clearly the dispersed oil droplet pattern can be observed in the readout from two of the three channels provided by the in situ fluorometer. Additional oil droplet size data analysis was to have been provided by Chris Fuller from Texas A&M University; however, it was never made available to MMS/OHMSETT personnel or to the NAS Dispersants Committee despite several requests. Figure 115 (photo file PA140163) shows the readout from the Turner 10-AU fluorometers at one and two meters, where dispersed oil droplets were measured at concentrations ranging from 20 to 30 ppm. Time-series fluorometer data were obtained by scientists from the UK oil spill cooperative (Oil Spill Response Limited), and those data are presented in Appendix 2 of the SL Ross final report (SL Ross et al., 2005). Examination of those fluorometer data corroborated the dispersed oil plume behavior and time-series trends described in this report.

Figure 116 (photo file PA140166) shows the mixture of dispersed oil and some minor splash over of non-dispersed surface oil in the secondary containment boom at the termination of Test No. 15. I estimate that of the surface oil trapped at the north end of the primary and secondary containment booms, only 5-10 percent is in the secondary containment area. Figure 117 (photo file PA140171) shows the view from the underwater view port near the north end of the containment boom 20 minutes after the termination of the test. Clearly there are still sufficient dispersed oil droplets to prevent observation of the containment boom from the underwater view port.

At 1427 hours, the entire tank is black, and looks like it contains oil. The non-dispersed surface oil at the north end of the tank is confined to a very thin silver sheen with the rest of the oil truly dispersed into the water column. Figure 118 (photo file PA140172) shows the discoloration of the water from the surface outside of the containment boom due to the advective transport and diffusion of the dispersed oil into the rest of the tank. Figure 119 through Figure 121 (photo files PA140176, 179, and 180) show the recovery of the residual non dispersed oil from inside the primary and secondary containment booms at the termination of this test. Compared to earlier test where the dispersants were not very effective and anywhere from 1 to 1.5 barrels of oil and water were collected, this test yielded only approximately half a barrel of recovered material. After allowing several weeks for the water to settle out, decanting the oil, and correcting for water content in the recovered oil, the final percent recovered value from this test was 55 percent (or 45 percent dispersed – Table 1). In addition, density measurements were completed on the oil to estimate the amount of oil lost to evaporation during the test, but it turned out that the measured density actually decreased slightly (SL Ross et al., 2005), so the data could not be used to estimate evaporative loss. Furthermore, water content in the collected oil (although measured and corrected for) can significantly affect oil density (Payne and McNabb, Jr. 1984; Payne et al., 1984) making this approach highly inaccurate. For these tests, this is probably a moot point, because with intermediate fuel oils, the anticipated evaporative loss would be extremely minimal anyway. Nevertheless, I did suggest (to Ken Trudel and OHMSETT personnel) that in addition to density measurements for estimating evaporative loss, it would probably be prudent to incorporate flame ionization detector gas chromatographic (FID GC) analyses of the oils before and after each test to further assess and more accurately quantify loss due to evaporation in the future.

Another series of photographs were taken from the underwater view ports between 1444 and 1446 hours, and Figure 122 (photo file PA140183) shows the view from the southernmost underwater view port (closest to the wave generator). Figure 123 (photo file PA140186) shows the view from the central underwater viewing port approximately in the middle of the test area where the containment boom and anchor chains are partially obscured due to the dispersed oil droplets. Figure 124 (photo file PA140188) shows the view from the northern-most underwater view port where the containment boom is still completely obscured from vision due to dispersed oil droplets. Clearly, the concentrations of dispersed oil droplets are not homogeneous throughout the tank. As the surface oil was driven by the waves toward the north end of the tank where it was eventually dispersed (with and without additional turbulence imparted by the waves interacting with the primary and secondary containment booms), higher concentrations of dispersed oil are encountered. It is also possible that a variety of circulation patterns can be set up within the tank, and they might be responsible for the transport of dispersed oil droplets from one part of the tank to another. This apparent gradient in dispersed oil concentrations was confirmed by the north-south fluorometer traces in Appendix 2 of SL Ross et al. (2005). In addition to the different concentrations of dispersed oil droplets observed throughout the tank, droplet particle size data would be very helpful in evaluating droplet number and size distributions with depth. Such data would be very useful in estimating dispersed oil droplet rise velocities, and ultimately allowing better extrapolation to at-sea conditions

Figure 125 (photo file PA140196) shows the view from the bridge at 1453 hrs looking down into the experimental test chamber and secondary containment zone after all the remaining (and recoverable) surface oil had been removed. Clearly the dark green-black color of the water will make it difficult to observe effective dispersion in future tests, and based on these observations from test No. 15, it is obvious why Ken Trudel and Randy Belore ran the heavier IFO 380 fuel oils and poorer performing dispersants first. When you have an effective dispersant applied to the oil it is VERY obvious, as the entire tank takes on the color of coffee, and it will become much more difficult to observe additional tests following a successful dispersant run.

Test No. 16 – IFO 180 plus Corexit 9500 (nominal DOR 1:50), intermediate (33 cpm) energy waves

Final preparations for this test (Figure 126 – photo file PA14197) were completed around 1516 hours, approximately 30 minutes after the tank cleaning was completed from the previous run. As shown by Figure 127 and Figure 128 (photo files PA140198 and 199) the water was still pretty dark green in color, and Figure 128 shows another example of one of the breaking waves (from the 33 rpm setting on the wave generator) observed before the initiation of the test. This test will be with IFO 180 fuel oil and Corexit 9500 at a nominal dispersant to oil ratio of 1:50 with the wave generator set at intermediate turbulence (33.4 cpm). The final calculated dispersant to oil (DOR) was 1:100 because approximately half the dispersant was sprayed directly into the water and not on the oil (Table 1).

The oil was gently laid down (dribbled) onto the water surface at 1518 hours (Figure 129 – photo file PA140201), and Figure 130 (a blow up of photo file PA140201) clearly illustrates that none of the oil is being "driven or injected" into the water at this oil discharge rate. However, it is also apparent from Figure 130 that there still is considerable silver sheen on the water surface as a result of the previous test concluded 30-40 minutes earlier. Figure 131 and Figure 132 (photo files PA 140202 and 203) show the appearance of the oil on the water surface immediately after the dispersant was applied. When viewed from the bridge looking from the south to the north, the water clarity appeared much better than it did in the previous photographs (Figure 127 and Figure 128 – photo files PA140198 and 199) when viewed from the bridge looking to the south. Even though this test was run at the higher energy of 33 rpm on the way generator, I did not notice very many whitecaps at the initiation of the test. Figure 131 through Figure 134 (photo files PA140202, 203, 205 and 207) show the appearance of the oil in the center of the tank during the first two minutes of the experiment. Even in the absence of significant whitecaps, there was evidence of oil dispersion occurring within the first few minutes (Figure 135 – photo file PA140208 taken two and one-half minutes into the test), particularly in areas where a broken wave had passed through the slick. Within five minutes of dispersant application, there was evidence of significant dispersion in localized areas (Figure 136 – photo file PA140213), and within seven minutes it appeared that over 90 percent of the surface oil had been dispersed throughout the tank (Figure 137 – photo file PA140219). Seven to eight minutes into the experiment, there was hardly any surface oil observed, but the water column was so dark that it was very difficult to clearly differentiate surface oil slicks from subsurface dispersed oil (Figure 138 – photo file PA140220). There was a lot of silver sheen at the surface, but the thicker oil observed in earlier runs with poorer performing dispersants and lower energy waves was clearly absent. It was obvious that there had been very successful dispersion even with the absence of very many breaking waves. Figure 139 (photo file PA140223) shows the more traditional coffee-with-cream color from the dispersion of oil droplets into the water column. This lighter brown color is believed to be due to finer oil droplet sizes obtained with the more effective Corexit 9500 at the higher turbulence regime, but unfortunately there were no dispersed oil droplet particle size data to confirm this hypothesis. Clearly, as shown in Figure 140 (photo file PA140226), there was significant dispersion throughout the tank in areas that were well away from any excess turbulence introduced by the containment boom. Also, as discussed before, the sampling and electrical cables for the fluorometers were carefully removed to avoid introduction of any excess turbulence during the initial sweep over the treated slick.

After the sampling tubes for the fluorometers were placed back into the water and additional transects completed, concentrations approaching 110 ppm were measured on the Turner fluorometers (Figure 141 – photo file PA140228). The maximum 1 meter-depth concentration was 110 ppm and the maximum 2 meter-depth concentration was 76 ppm. The background fluorescence signal before the test was initiated was about 30 ppm at 2 m and 40 ppm at 1 m. Clearly, there was still a lot of dispersed oil in the tank from the previous successful test before Test No. 16 was undertaken, but the UV fluorescence measurements were capable of easily differentiating the background signal from the freshly dispersed oil obtained in this experiment. In complete agreement with the visual and photographic observations documenting the extensive dispersed oil plumes in the northern and central section of the tank, the north-south fluorometer transects in Appendix 2 of SL Ross et al. (2005) also showed the time-series accumulation of dispersed oil plumes at 1- and 2-meter depths extending 20-30 meters southward into the center of the tank, and the concentrations were twice as high as they were in Test No. 15.

Figure 142 (photo file PA140229) shows one of several separate water samples that were grabbed from the effluent from the 1 meter-depth Turner fluorometer for independent calculation of water column concentrations by EPA method 418.1 (carbon tetrachloride solvent extraction and infrared spectrophotometry). Oil droplets in the 0.5 mm and larger size range could easily be observed with the naked eye in the 1-meter grab samples, while the 2-meter grab sample (Figure 143 – photo file PA140231) appeared clearer. Figure 144 (photo file PA140233) shows the in situ fluorometry data obtained from a transect through part of the dispersed oil plume with the Wetlabs FL-3 fluorometer attached to the LISST particle size analyzer at a depth of two meters. As noted earlier, it was extremely disappointing that Texas A&M University ultimately chose not to share any of the oil droplet size distribution data from this test despite several requests from members of the NRC panel on dispersant efficacy and effects. If those data had been released, it may have been possible to see if, in fact, the size distribution is smaller than that observed in the previous test with Superdispersant-25 where the dispersion was a darker black in color compared to the light coffee-with-cream color observed in this test. Figure 145 through Figure 149 (photo files PA140236, 243, 244, 253, and 259) show the appearance of the dispersed oil below the water surface over the next 10-15 minutes (through the 30 minute period of the test). Most of the oil was effectively dispersed, and there was very little oil observed on the surface at the termination of the test. There were traces of sheen and a few patches of residual thin oil films adjacent to the containment boom (Figure 148 – photo file PA140253), but the surface chop and capillary waves throughout the rest of the tank clearly showed that most of the oil was dispersed into the water column. Figure 150 (photo file PA140262) shows the in situ fluorometer printouts from another transect through the dispersed oil plume. At the termination of the test, the water was extremely dark, with a green or black hue everywhere throughout the tank (both inside and outside of the containment booms) as shown by Figure 151, Figure 152, and Figure 153 (photo files PA140269, 270, and 271). Close examination of Figure 154, Figure 155, and Figure 156 (photo files PA140275, 278 and 280) clearly demonstrate that there was VERY LITTLE residual surface oil that could be herded to the northern end of the containment boom and vacuum collected at the termination of the test. As before, oil in the secondary containment zone was collected and combined with the surface oil from the primary containment zone to give a quantitative estimate of the nondispersed oil. I would estimate that no more than four or five liters of oil were collected from the primary test zone and perhaps one liter of oil was collected from the secondary containment zone. As shown by the data in Table 1, only 16 percent of the initially added oil was recovered yielding a value of 84 percent dispersed (or otherwise not recovered).

Figure 157, Figure 158, and Figure 159 (photo files PA140288, 289, and 291) show the water as viewed from the underwater view ports starting at the south end of the tank closest to the wave generator (Figure 157), the middle of the tank (Figure 158), and the north end of the tank closest to the primary and secondary collection areas (Figure 159). The southernmost view port was fairly clear, and it was easy to see the containment boom and anchor chain. In the middle zone, the boom was still visible, but there were countless small but finite oil droplets that could be observed through the view port. At the northern end of the tank, it was impossible to see the containment boom from the underwater view ports due to the high concentrations of dispersed oil droplets in the water. Oil droplets with sizes from 0.5 to 1 mm could be observed everywhere in the water column. Also, unlike yesterday's tests with the poorer performing dispersants, the oil did not resurface in bulk (or even a mosaic pattern) after the cessation of turbulence. The tank instead, is pretty much just jet black due to the oil throughout the water column (Figure 160 – photo file PA140286). The wave tank was then allowed to stand quietly overnight, and as discussed in the following tape notes for October 15, 2003, I arrived early the next morning to document any resurfaced oil before any tank cleaning measures could be undertaken.

Tape Notes from October 15, 2003

Documentation of resurfaced oil fifteen hours after the termination of Test No. 16.

It's now 0703 hours, and I arrived early this morning to observe any resurfaced oil before OHMSETT personnel could initiate any maintenance or cleanup activities on the tank. At this time, the tank has been standing quiet for over 15 hours. Figure 161 through Figure 167 (photo files PA150001, 2, 4, 5, 8, 9, and 10) were taken between 0711 and 0718 hours, and they document the limited extent of oil resurfacing that occurred overnight. There was a fine silver sheen from extremely thin oil layers both inside and outside the containment booms; however, the oil had not resurfaced in bulk to the same extent as that observed after the earlier runs completed yesterday with the poorer performing dispersants (e.g., Figure 56 after Test No. 12). That is, there were no agglomerations of large oil patches like the ones observed the day before. I don't know for a fact if this surface oil sheen would be dispersed upon reintroduction of wave turbulence (a test that should be run sometime in the future), but I suspect that if minor wave turbulence had been continued overnight, much of it certainly would have remained in suspension in the water column. The water clarity when viewed from the three underwater view ports was still opaque due to the high concentrations of dispersed oil droplets throughout the water column, and at this time (after over 15.5 hours), the containment boom could not be seen even from the southernmost view port closest to the wave generator (Figure 168 – photo file PA150013). At the termination of yesterday's tests, the containment boom and anchor chain were clearly visible from this location (see Figure 157 – photo file PA140288), indicating that the dispersed oil has continued to diffuse laterally and longitudinally throughout the tank overnight. When viewed from above, the water still has a darker green-black appearance suggesting that there is still a lot of dispersed oil throughout the water column.

The silver sheen observed along the edges of the tank between the tank wall and containment booms was no doubt due to resurfacing of minor amounts of the dispersed oil (see Figure 169 and Figure 170 – photo file PA150014 and an enlargement). The colors in those figures are reflections from the clouds at sunrise and not colored oil sheen. Figure 170 allows examination of the oil film and small droplets that have formed on the water surface after 15.5 hours of relative quiescence (protected from the wind) in the lee along the western side of the tank wall. The wind has been blowing briskly from the west and southwest throughout the night, which causes some surface ripples and disturbance within the test zone. There appears to be less surface oil sheen inside the containment boom than outside the test zone between the boom and the tank walls (Figure 171 – photo file PA150015), again suggesting that the finite dispersed oil droplets that had been advected and defused outside of the swept test area have come back to the surface overnight. In actual fact, however, it looks like the dispersed oil that resurfaced inside the containment boom was blown to the northeast corner by the southwesterly winds overnight and trapped inside the test boom (Figure 172 through Figure 174 – photo files PA15001717, 20, and 23). I don't know if this oil was subsequently manually collected after these photos by OHMSETT personnel or simply washed from the containment zone and outside of the general test area during preparations later this morning for the rest of today's experiments. However, with 20:20 hindsight, it would have been prudent to collect this additional volume (estimated at two or three liters (see Figure 173 and Figure 174 taken at 0727-8 hours) separately to help quantify dispersed oil droplet resurfacing behavior. It should be stressed, however, that the resurfaced oil volume was very minor compared to the total oil introduced into the tank for the test or the total oil recovered from control tests with no dispersants or the earlier low-energy tests with poorer performing dispersants.

Figure 175 (photo file PA150024) shows the general tank condition, before I went into the offices to attend a planning meeting to discuss today’s testing activities. As shown by Figure 176 and Figure 177 (photo files PA150030 and 31) taken an hour later at 0833 hrs after the residual surface oil shown in Figure 173 and Figure 174 had been herded out of the test area, the water is still very dark from the dispersed oil droplets remaining in the water column from yesterday’s tests. It is also apparent from the ripples on the water surface in Figure 177 (photo file PA150031) that the wind (gusting between 20 and 30 knots) did not impart a lot of surface energy to the tank. This is probably due to shielding by the tank walls and the limited fetch across the east-west dimension of the tank.

Test No. 17 – IFO 120 plus Corexit 9500 (nominal DOR 1:50), low (30 cpm) energy waves

It's now 0940 hours and OHMSETT/SL Ross personnel are preparing for test No. 17 (Figure 178 – photo file PA150032). This test will be undertaken with a slightly lighter fuel oil (IFO 120, viscosity 1,145 cP @ 16^{o} C, see Table 2) and Corexit 9500 at a nominal dispersant to oil ratio of 1:50. This lower viscosity oil spread out on the water better providing more of a target for the dispersant, but because of strong winds much of the dispersant was blown away resulting in a measured DOR of 1:63 (Table 1). The wave generator was set at the lower energy regime of 30 cpm. Based on the results from the at-sea trials, the investigators were anticipating that they were going to get pretty good dispersion even at the lower energy wave frequency with this lower viscosity oil. The test was initiated at 0946 hours (Figure 179 and Figure 180 – photo files PA150035 and 36) with the oil being laid down after the wave train was established. Figure 181 (photo file PA150040) shows the dispersant spray application photographed from the western side of the observation dock. Under the heavy westerly wind conditions (steady 20-30 knot winds with guests to 40 knots) a significant amount of the dispersant was blown away from the slick and drifted to the east. Nevertheless, close examination of Figure 181 (photo file PA150040) shows that despite the wind, reasonable surface coverage of the dispersant hitting the oil and water occurred.

Within two-three minutes of the dispersant application, it was clear that although the oil was drifting with the wind towards the east side of the experimental zone, it was also readily dispersing into the water column (Figure 182 – photo file PA150042). Also, note that the containment boom has been forced by the winds against the eastern edge of the tank. Figure 183 and Figure 184 (photo files PA150045 and 46) show the dispersed oil plume along the eastern edge of the experimental zone four minutes after dispersant application. At 0954 hours, we did a fast pass with the bridge over the treated slick, and because of the strong wind, a lot of the oil was observed to drift to the east side of the tank; however, it is very obvious that a significant amount of dispersion was obtained. Perhaps because of the wind causing some of the dispersant to miss the slick or because of the lower wave turbulence conditions (30 cpm), not all of the IFO 120 fuel oil was immediately dispersed, and a fair amount of nondispersed surface oil accumulated along the eastern containment boom. Figure 185 and Figure 186 (photo files PA150050 and 55) show this surface oil along the eastern edge of the experimental test zone looking towards the south (wave generator) end of the tank. Although it looked like there was good dispersion initially, the wind did blow a significant amount of nondispersed oil against the boom along the side of the tank. With continued wind and wave turbulence, however, the surface oil adjacent to the eastern-most boom was also eventually dispersed in the water column over the next 6-10 minutes (Figure 187 and Figure 188 – photo files PA150056 and 59). In this instance, it is very likely that some additional turbulence imparted by the movement of the boom adjacent to the oil under the low-energy wave conditions enhanced the dispersant effectiveness. Figure 189 (photo file PA150066) shows the water surface and dispersed oil plume along the eastern side of the containment boom and tank wall 20 minutes into the test. Figure 190 and Figure 191 (photo files PA150071 and 72) show the residual non-dispersed surface oil collected within the primary and secondary containment zones during the test.

Figure 192 (photo file PA150078) shows the continuous readouts from the in situ fluorometer, where the dispersed oil cloud can be readily observed on the upper and lower channels.

Interestingly, the best readouts were obtained with the TPH channel (upper readouts in blue) and the total dissolved organic matter (TDOM) channel (lower readout in red). The fluorescein channel, which is also the chlorophyll A channel, (middle in green) was noisier and didn't give as steady a signal. The LISST-100 particle size analyzer showed values approaching 2000 and up to 5700 at one point. It was hoped that complete data analysis of the LISST-100 readouts would be provided by Chris Fuller of Texas A&M University; however, that information was never provided so it is impossible to know exactly what those values represented. The 1- and 2-meter fluorometers initially showed values around 4 ppm and increased to around 13-17 ppm on the second pass through the dispersed oil cloud, but clearly with this wind blowing most of oil to the side of the tank we didn't get the kind of dispersion that we saw yesterday. This dispersant test clearly was not as successful as test No. 16, which we observed yesterday at the end of the day with less wind and Corexit 9500 at higher energy. The U.S. Coast Guard fluorometer started with a background reading of around 30 before entering the plume, shot up to around 120-130, and then returned to around 60 after the sampling tube passed through the plume. From the south end of the tank looking north (Figure 187 and Figure 188 – photo files PA150056 and 59), it looks like better dispersion was obtained than when viewed from the north end of the tank looking south with the differential reflection of sunlight on water and residual non-dispersed surface oil (for example, see Figure 185 and Figure 186 – photo files PA150050 and 55).

At 1007 hours when we passed over the test zone, there wasn't near as much oil along the eastern edge of the boom as there was before (see Figure 186 — photo file PA150055 looking south toward the wave generator vs. Figure 189 – photo file PA150066 looking north toward the control tower). There's definitely a dark cloud from the dispersed oil adjacent to the boom. By 1010 hours there wasn't any more oil along the eastern edge of the boom. Because of the noticeable slick drift to the east, Ken Trudel and Randy Belore moved the intakes for both fluorometers all the way over to the right (facing north) so that they would be in the center of the plume along the eastern edge of the test zone. There is some oil accumulating in the northeast corner of the containment zone (Figure 190 and Figure 191 – photo files PA150071 and 72), and that's probably the nondispersed oil, which had been along the side of the tank being forced to the north by the wave train. While there was a fair amount of oil that was accumulating in the northeast corner of the primary containment zone, there was no evidence of excessive splash over of the oil into the secondary containment zone at 1010 hours (Figure 191 – photo file PA150072). Maximum signals on the 1-meter and 2-meter fluorometers ranged from 25-28 ppm during the next (3rd) pass through the dispersed oil plume along the eastern one-third of the tank (with the fluorometer sampling tubes moved to the east to more accurately intercept it). The fourth transect through the dispersed plume was started at 1015 hours. Background levels were 5 and 6 ppm at the beginning of the transect (at the north end of the experimental test zone) at the one and two meter depth, respectively. During the fourth pass (from the north end towards the south), the fluorometer readings generally stayed in the 5-6 ppm range until we got closer to the middle and southern end of the tank where it was possible to visibly see higher concentrations of dispersed oil in the water column. At that time, the fluorometer readings went to 22 ppm and 18 ppm for the 1-meter depth and 2-meter depths, respectively. (Also see the fluorometer transect traces in Appendix 2 of SL Ross et al., 2005.) The Coast Guard fluorometer at one meter yielded values ranging from around 60 to 120, but they were not calibrated concentrations in units of ppm, and instead were based on a fluorescein dye calibration performed earlier. Figure 192 (photo file PA150078) shows the traces from the in situ fluorometer at 2 meters during pass four.

Obviously the dispersed oil cloud is very patchy, but with this wind, it looks like there is more dispersed oil at depth than what was observed earlier. The winds are averaging around 18 knots with gusts approaching 40 knots recorded during the middle of the run.

By 1025 hours there was hardly any oil on the surface throughout most of the tank (Figure 193 – photo file PA150079), however, a fair amount of residual nondispersed oil had been naturally herded down to the northeast corner of the tank by the combination of wind and wave action. Figure 194 (photo file PA15082) shows the surface oil that had naturally accumulated in the northeast corner during the test, and Figure 195 (photo file PA150085) shows the additional oil herded into that corner after fire monitor spraying for collection and quantification of the nondispersed oil. As shown in Figure 195 and Figure 196 (photo files PA150085 and 89), there was very little oil splash over into the secondary containment zone. Nondispersed oil collections were completed between 1033 and 1037 hours, and as shown by the data in Table 1, a dispersant effectiveness of 39 percent was calculated (or 61 percent of the oil originally added was recovered after correcting for water content and evaporation of the more volatile oil fractions).

Test No. 18 – IFO 120 plus Corexit 9500 (nominal DOR 1:50), intermediate (33 cpm) energy waves

The time is 1214, and the OHMSETT/SL Ross personnel are beginning preparations for test No. 18 (Figure 197 and Figure 198 – photo files PA150096 and 99). This test will again utilize the lower viscosity IFO 120 fuel oil plus Corexit 9500 (at a nominal dispersant to oil ratio of 1:50), but under an intermediate wave turbulence regime with the wave generator set at 33.3 cpm. The wind is blowing pretty steadily out of the west-southwest (gusting to 30-35 mph), and the containment boom is partially deflected in a bow pattern towards the center of the tank. In addition, OHMSETT personnel are required on the east side of the tank to fend the boom away from the tank wall (see Figure 198). Even though the wave generator is set at 33 cpm and there is a steady wind, there are very few whitecaps observed in the tank.

The test was initiated at 1217 hours with the oil discharged to the established wave pattern (Figure 199 – photo file PA150100), and the dispersant was applied over a 60 second period (Figure 200 – photo file PA150102). As in the previous test completed earlier this morning, there is a lot of dispersant drift due to the high wind conditions. Figure 201 through Figure 204 (photo files PA150108, 109, 110, and 111) show the surface slick and dispersed oil behavior observed from the dock and experimental sampling bridge over the first three minutes of the experiment. Even though it was obvious that a fair amount of dispersant did not hit the oil and swirled around the bridge in the high wind conditions, it looks like enough dispersant contacted the oil to cause a reasonable dispersion. The Coast Guard fluorometer was positioned to be under the main part of the dispersed oil plume, and the lowest background reading in clean water before the test was around 50. As they went through the center of the dispersed oil plume, the value increased to 246 (based on a fluorescein dye calibration). Visual observations on the Turner fluorometers inside the bridge (sampled at depths of 1- and 2-m) showed maximum readings of ~60 ppm starting from a background concentration of 6-10 ppm in cleaner water. Complete time series data from these fluorometer measurements are provided in Appendix 2 of SL Ross et al. (2005).

Figure 205 (photo file PA150117) shows the appearance of the dispersed oil plume immediately below the bridge approximately five minutes after dispersant application. As in yesterday afternoon's tests with more effective dispersants, a coffee-with-cream colored plume was observed in this test. As noted before, this is believed to be due to finer oil droplet particle size distribution; however, that hypothesis cannot be confirmed because the final data from the LISST-100 particle size analyzer were never released by Texas A&M University. Because of the high winds, a limited amount of nondispersed surface oil was observed collecting along the eastern containment boom and in the northeast corner of the primary experimental zone (Figure 206 – photo file PA150121). Significant signals from dispersed oil droplets were observed in all three in situ fluorometer channels (Figure 207 – photo file PA150122), and discrete water samples were collected (during fluorescence maxima) from the effluent of both the one- and two-meter Turner fluorometers for independent analysis of hydrocarbon concentrations by EPA method 418.1 (Figure 208 and Figure 209 – photo files PA150123 and 124). Observed maximum fluorescence readings of 69-70 ppm occurred during the sampling interval. Figure 210 (photo file PA150129) shows the three-channel in situ fluorometer readouts obtained during the same time period. Figure 211, Figure 212, and Figure 213 (photo files PA150133, 138 and 144) show the appearance of the surface slick and dispersed oil plume over the 13 through 20 minute elapsed time period. Clearly the presence of the dispersed oil plume in the water column can be observed both inside the containment zone and outside (Figure 214 – photo file PA150145). There was a small amount of oil that was not dispersed, and it can be observed accumulating along the eastern and northeastern edge of the boom in Figure 215 and Figure 216 (photo files PA150147 and PA150150) photographed near the termination of the test. Figure 217 and Figure 218 (photo files PA150151 and 152) show the surface nondispersed oil collecting in the northeast corner of the primary containment boom approximately 23 minutes into the test. As shown in Figure 218 (photo file PA150152), very little oil splashed into the secondary containment zone.

Unfortunately, this test had to be terminated and the wave generator turned off after only 24-25 minutes (instead of the usual 30 to 35 minutes) because the line securing the southwest corner of the containment boom separated under the strain from the heavy cross winds, and the western portion of the boom collapsed over the next six minutes as shown in Figure 219 through Figure 227 (photo files PA150156, 158, 160, 161, 162, 163, 165, 168, and 171). This made collection of the nondispersed oil over the next 25 minutes much more difficult as shown in Figure 228 through Figure 235 (photo files PA150175, 181, 182, 183, 185, 187, 190, and 192). Nevertheless, OHMSETT and SL Ross personnel attempted to complete as quantitative a recovery of nondispersed oil from as much of the collapsed boom as possible. Because of these problems, however, the final quantitative recovered oil values for Test No. 18 are apt to be subject to more error that the previous tests completed at the facility. During the water spray operations to drive the oil into the northeast corner for collection, I noticed that some water spray did inadvertently drive the oil from the primary collection area into the secondary collection zone. I estimate that the final surface oil in the secondary collection zone was less than 15 percent of the total oil collected. As before, however, the oil in the secondary containment zone was included with the overall collection of nondispersed oil as shown in Table 1. There was also an unknown amount of oil trapped between the collapsed boom sections at the southern end of the tank, and unfortunately, it could not be included in the final collection total (Figure 236 and Figure 237 – photo files PA150195 and 196). I'll give them this though, for a busted run, they did the best they could to recover as much oil as possible, and 34 percent of the initially added oil was recovered yielding a dispersed (or lost) oil value of 66 percent. Based on my observations and photographic documentation before the boom collapsed, I believe that most of the non-dispersed oil was at the northern end the tank, and there was a significant subsurface dispersed oil plume throughout the center of the test area. This was confirmed by the fluorescence transect data for Test No. 18 in Appendix 2 of SL Ross et al. (2005). One last quick observation from the underwater viewing ports: millions of tiny (< 0.5 mm) sized droplets were observed suspended in a random and gently swirling motion in the water column in front of the windows (no photographs were taken) even though the wave generator had been turned off for over 40 minutes.

It should be noted that Test No. 18 was added as an extra data point. It wasn't a part of the original test matrix, but the investigators thought they would like to obtain additional data on the lighter, less viscous fuel oils if they could. It was also the second of two "Visitor's Days" so they hoped that (despite the winds) the test would provide additional training for the Coast Guard personnel and an observational opportunity for the EARLE navy base personnel who were present this afternoon. Unfortunately, the winds all day were really at, or outside the edge of the normal workable range, and a lot of the dispersant never came in contact with the oil. During Test No. 18, winds were steady at 30-34 knots out of the west with measured gusts to 50 knots. There was sufficient energy from the wind and enough sail area on the boom to move the bridge holding it at the southern end of the tank about six feet to the north even though the hand breaks on the railroad wheels were set, and they were blocked with wheel blocks.

Tape Notes from October 16, 2003

OHMSETT personnel had re-secured the boom that had broken free during yesterday afternoon's last experiment (Test No. 18) before I arrived at 0830 hours this morning. The water in the test tank still had a dark green color (Figure 238 – photo file PA160002), but it had cleared sufficiently such that the containment boom and anchor chain could again be observed from the underwater window (Figure 239 – photo file PA160006) in the center of the tank.

The winds this morning are light and variable, mostly out of the west at 8 to 10 knots. There is only a light a ripple from the wind on the water surface in the tank, and the conditions are significantly better than they were yesterday. Figure 240 (photo file PA160010) shows a minor amount of surface oil that was still inside the primary containment zone, and Figure 241 (photo file PA160016) shows a very significant slick between the western containment boom and tank wall that was evidently dispersed oil that had resurfaced over night. I suspect that this represented dispersed oil that resurfaced in the 19 hours since the end of Test No. 18 while the containment boom was still collapsed against the eastern tank wall overnight (see Figure 236 and Figure 237). Then, as the boom was pulled away from the wall this morning and repositioned as shown in Figure 238, the resurfaced oil was deflected and corralled into the concentrated band between the boom and tank wall as shown in Figure 241. It would have been very informative to have collected this oil to help quantify resurfacing behavior, but instead, the fire monitors were used to drive this out of the test area and underneath the permanent boom curtain at the extreme north end of the tank (Figure 242 – photo file PA160017). As shown in Figure 242, the tank was free of any surface oil after this final polishing, but the water still had a dark green cast to it.

Dispersant Dosage Control Investigation

Figure 243 (photo file PA160004) shows the apparatus used to control the dispersant application for each run. The large white rectangular container is used to hold the dispersant, which is circulated through the plumbing shown in the figure at a pressure monitored through the pressure gauge shown just to the right of the dispersant reservoir. Once the appropriate pressure was established a valve was opened to direct the neat dispersant to the 5-meter long spray bar located below the bridge approximately 1 1/2 m above the water surface (Figure 244 – photo file PA160008). The volume of dispersant applied was calculated by measuring the change in height of the dispersant level in the white rectangular reservoir. A tape measure (Figure 245 – photo file PA160185) permanently mounted inside the reservoir is used for this measurement.

Figure 246 (photo file PA160013) shows the pressure gauge mounted on the spray bar for dispersant applications. Later, during actual tests, photographs will be taken of the pressure gauge on the dispersant flow control unit (Figure 243 – photo file PA160004) and on the spray bar (Figure 246 – photo file PA160013) to document any pressure drop from the dispersant pump to the spray bar itself. The spray nozzles and pressure settings used for all the tests are considered in more detail in the following paragraphs.

Dispersant dosage is controlled by selection of different spray nozzles and application pressures. Industry standard UniJet flat spray nozzle tips (from UniJet Spraying Systems) are used on the spray bar, and Figure 247 shows a scanned copy of the UniJet Spray Nozzle Tip specification data sheet for the nozzles used in these tests. These are the same spray nozzles that are used in real-world applications of dispersants during an actual oil-spill response in the field. Two different spray nozzle sets were utilized for the tests completed at OHMSETT. For the majority of the tests completed at a nominal dispersant to oil ratio of 1:50 (up to this point), UniJet spray nozzle model No. 8001 at a pressure of 30 psi was used. As shown in Figure 247, each nozzle at this pressure is designed to deliver 0.09 gallons per minute (gpm). Figure 248 (photo file PA160103) shows a close-up of one of these nozzles, and Figure 249 (photo file PA160104) shows the spray bar with eleven of these nozzles in place after it was pulled up to the movable bridge rail for adjustment. This configuration will deliver a nominal 1 gallon per minute total (0.09 gpm/nozzle x 11 nozzles = 0.99 gpm) from the eleven nozzles. Figure 250 (photo file PA160100) shows a close up of UniJet spray nozzle 80015 which was used to deliver a higher nominal dispersant application for Test No. 19, where twice the nominal dispersant dosage (DOR = 1:25) was desired. As shown on the spec sheet in Figure 247, this configuration at a pressure of 60 psi is designed to deliver 0.18 gallons per minute from each nozzle. Again there are 11 nozzles equally spaced along the 5-m spray bar, so for a 60 sec. application, this configuration delivers a nominal 2 gallons (1.98 gal) of dispersant. The actual volume of applied dispersant is double checked by measuring the change in height (used to calculate the volume) in the white dispersant reservoir (see Figure 251 and Figure 252 – photo files PA160184 and 185) before and after each test. .

Test No. 19 – IFO 180 plus Corexit 9500 (nominal DOR 1:25), low (30 cpm) energy waves

This test will be undertaken with IFO 180, Corexit 9500, and low (30 cpm) energy wave conditions; however, the target or nominal dispersant-to-oil ratio will be higher at 1:25. Therefore, for Test No. 19 it was necessary to replace the red UniJet model 8001 nozzles used in the previous tests with the yellow UniJet nozzle model No. 80015 shown in Figure 250 (photo file PA160100). As note above, the UniJet flat spray nozzle model 80015 is designed to deliver a nominal 0.18 gallons per minute per nozzle at an application pressure of 60 psi (see Figure 247). With 11 nozzles on the spray bar and a 60 second application, that yields a nominal 2 (1.98 gallons) of dispersant. But in fact, the actual volume of dispersant in the spray controller reservoir is measured before and after each test to confirm the final application volume and rate, and thus, allow a more accurate measurement of the DOR as shown in Table 1. The DOR values in Table 1 are also corrected for the patchy oil distribution on the water surface, which causes a significant fraction of the dispersant to miss (underdose) the oil and go directly into the water.

The purpose of this run was to expand the database obtained from the low end of the energy spectra. This oil was not dispersed effectively at this energy level at the lower DOR of 1:50 tested previously. Therefore, the investigators wanted to see if the overall dispersant effectiveness would be improved by doubling the dosage rate under these low energy conditions. If the results from this test show significantly improved dispersion, then one of the other dispersants that was less effective previously (e.g., Superdispersant-25) may be retested at this higher dispersant to oil ratio (and lower energy regime) as well. [In actual fact this was not done because (as described below) the dispersant didn't work that well under these lower-energy conditions even at the higher DOR, and instead, the final test for the day involved a replicate run with the higher viscosity IFO 380 fuel oil at a dispersant to oil ratio of 1:50.]

Preparations for Test No. 19 were completed around 0925 (Figure 253 – photo file PA160009), the low-energy wave train was established (Figure 254 – photo file PA160021), and the test was initiated at 0938 hours (no oil addition photo is available because I was documenting the dispersant spray pressures). Figure 255 (photo file PA160022) shows the pressure reading of 57 psi obtained on the dispersant flow control system on the bridge, and Figure 256 (photo file PA160026) shows the pressure reading measured on the spray bar (also 57-8 psi) during dispersant application. Figure 256 also shows the uneven distribution of the IFO 180 fuel oil on the water surface as it passed beneath the spray bar. As described previously, this results in under dosing of the oil because much of the dispersant actually lands on the water; however, this reduction in the actual application rate was corrected for in the final data analysis and report prepared by SL Ross et al. (2005) and the data shown in Table 1. Ken Trudel photographed the oil from each run as it passed under the bridge before it was treated by the dispersant, so the average surface oil coverage, thickness, and actual dispersant to oil ratio can be calculated for each test. Just as was done for accurate measurement of the dispersant volume, the oil volume discharged in each test was calculated by measuring the change of oil volume in the oil reservoir before and after each test.

Figure 257 and Figure 258 (photo files PA160029 and 33) show the surface oil as viewed from the bridge during the first four minutes of the test. There was no significant dispersion observed. Figure 259 (photo file PA160035) shows the nondispersed oil (looking from the south to the north) accumulating near the eastern edge of the containment boom five minutes after dispersant application. Figure 260 (photo file PA160039) shows the appearance of the oil adjacent to the eastern edge to the boom when looking from the north to the south (towards the wave generator) six minutes after dispersant application. Figure 261 (photo file PA160043) was taken from the observation platform located another 15 feet in the air above the moving oil/dispersant application bridge. This photograph (looking from the north to the south), taken 9 minutes after dispersant application, shows no significant dispersion. The oil was collecting along the eastern containment boom because of the prevailing 8-10 knot westerly wind, and with time, most of this oil migrated to the northern end of the test zone (and adjacent to the secondary containment boom) under the influence of the wind and surface waves (Figure 262 – photo file PA160051). As shown in the figure, little or no oil escaped into the secondary containment zone. Figure 263 (photo file PA160054) was taken approximately 13 minutes after dispersant application, and the influence of the moderately increased turbulence generated by the waves interacting with the containment boom can just begin to be observed. Over this time frame, a little more of the surface oil was dispersed into the water column as manifest by the darkening water color between the containment boom and the edge of the test tank. Part of this apparent dispersion is accentuated by the shadow from the eastern wall of the tank; however, it is further documented by the dispersed oil advecting and diffusing to the center of the tank as shown in Figure 264, Figure 265, and Figure 266 (photo files PA160061, 63, and 64). In these latter photographs, which were shot 22-23 minutes after dispersant application, the effect of the shadow from the wall is minimized. By 1001 hours almost all of the surface oil had been driven by the wind and waves to the northeast corner of the experimental test zone. Figure 267 (photo file PA160066) shows the surface oil trapped inside the primary containment zone along with some dispersed oil diffusing underneath the boom towards the side of the tank. Because of the boom effect, which was acknowledged by both Ken Trudel and Randy Belore to be an artifact of the test conditions (imparting more energy to the northeast corner), this test was NOT scored as reflecting significant or successful dispersion, and as a result, the other low-energy higher DOR test with Superdispersant-25 was canceled. As further confirmation, it should also be noted that the UV fluorescence measurements from the Turner fluorometer showed very little dispersed oil (10-15 ppm), and it was mostly limited to the northern end of the tank at the 1-meter depth although there appeared to be more diffusion of dispersed oil at a lower concentration (6-8 ppm) into the center of the tank at 2-meters (Appendix 2 of SL Ross et al., 2005).

Figure 268 through Figure 273 (photo files PA 160075, 77, 79, 82, 86, and 87) show several more photographs of the minimal dispersed oil cloud near the center of the tank, the collected oil at the northeast corner of the test zone, and its recovery using the vacuum system for later non-dispersed oil measurements by OHMSETT personnel. Because this oil is just at the verge of being easily dispersed (with only just a little bit more energy required) Randy Belore and the OHMSETT personnel were particularly careful not to disturb the surface oil during collection. The spray from the fire monitors was directed a minimum ten meters away from the oil to impart just a slight ripple effect to help herd the oil into the corner.

The results of test No. 19 demonstrated that doubling the dispersant-to-oil ratio to a nominal 1:25 did not significantly increase dispersion efficiency, and as shown by the data in Table 1, over 64 percent of the added oil was recovered leaving 36 percent as dispersed or otherwise not recovered. Also, as noted above, much of the dispersion was attributed to enhanced localized turbulence affecting the oil near the corner of the containment boom near the end of the test. This does demonstrate, however, that Corexit 9500 tended to remain with the oil for at least the 45-50 minute duration of the test. By way of comparison, Test No. 14 run with the same oil, energy regime, and dispersant (but at a nominal DOR of 1:50), yielded a dispersed oil value of 21 percent. Given all the uncertainties and sources of error (uncontrolled oil loss), there is no statistically significant difference in the measured dispersant effectiveness values of 36 and 21 percent for these two tests, and in Test No. 14 the dispersant-treated oil tended to remain more in the center of the tank (see Figure 72 through Figure 89), so the influence of increased localized turbulence from the boom interacting with the passing wave train did not result in enhanced entrainment of oil trapped against the boom until the last 10-12 minutes of the test. Also, it should be noted that to be accurate, the actual DOR for Test 19 was probably lower than 1:25 because some of the dispersant drifted away from the oil, and the oil distribution on the water surface was patchy, such that a lot of the dispersant went into water. Nevertheless, the wave turbulence at 30 cpm was not sufficient to generate a successful and complete dispersion even at the higher dispersant-to-oil ratio.

Test No. 20 – IFO 380 plus Superdispersant 25 (nominal DOR 1:50), intermediate (33 cpm) energy waves

This test will be undertaken with the higher viscosity (7,100 cP at 16^{o} C) IFO 380 fuel oil (Table 2), Superdispersant-25 at a dispersant to oil ratio of 1:50, and the intermediate wave turbulence regime with the wave generator set at 33 rpm. The UniJet spray nozzles were changed back to the model 8001 set before this test was initiated. Because of the higher oil viscosity, it was necessary to heat the oil to 70-72 degrees Fahrenheit with a band heater placed around the bottom of the drum (Figure 274, Figure 275, and Figure 276 – photo files PA160107, 110 and 108) to get it to flow through the oil discharge manifold nozzles. Figure 277 (photo file PA160112) shows an OHMSETT technician recharging the dispersant reservoir with Superdispersant-25, and Figure 278 (photo file PA160118) shows brief testing of the dispersant spray system in preparation for the test. Note that there are some gaps in the spray pattern that hits the water surface with the red UniJet Model 8001 flat spray nozzles. This further lowers the actual dispersant to oil ratio.

This test is actually a repeat of a test that was undertaken last week when they had to lay the oil out in three separate passes because of problems associated with pumping the higher viscosity fuel oil.

The wave generator was turned on for test No. 20 at 1145 hours and by 1150 hrs an adequate wave train was established to initiate the test (Figure 279 – photo file PA160122). As before at this wave generator setting (33.5 cpm), an occasional whitecap was noted in the center of the tank. The background reading on the 1-meter fluorometer before the test was around 4 ppm, and the background reading on the 2-meter fluorometer was 9.3 ppm. The test was initiated 1158 hours, and the dispersant was applied to the heavy fuel oil at a measured pressure of 33-4 psi at the spray boom (Figure 280 and Figure 281 – photo files PA160128 and PA160130). Note the very stringy and uneven distribution of the heavy fuel oil on the water surface in Figure 281 (photo file PA160130. Figure 282 through Figure 286 (photo files PA160132, 134, 135, 138, and 140) show the appearance of the IFO 380 fuel oil over the next three minutes. Initially the oil was observed to spread out more uniformly (Figure 283 – photo file PA160134), and then three minutes into the test it began to disperse into the water column as manifest by the lighter brown coloration noted in Figure 285 and Figure 286 (photo files PA160138 and 140). By 1204 hours, I estimate that most of the surface oil had dispersed into the water column. The other significant manifestation of the dispersed oil behavior was that it remained primarily in the center of the tank (Figure 287 and Figure 288 – photo files PA160144 and 147) and was not driven by the wind to the eastern containment boom like the lighter (IFO 180) fuel oil was earlier in the morning with Test No. 19 (higher dispersant-to-oil ratio and lower energy regime). Figure 289, Figure 290, and Figure 291 (photo files PA160151, 153 and 156) show the dispersed oil plume when observed from the 15-foot observation platform mounted on the test bridge, and clearly, the lighter chocolate-brown color of the dispersed oil can be differentiated from a narrow band of nondispersed surface oil that had been blown closer to the eastern containment boom over the first eight minutes of the test. Figure 292, Figure 293, and Figure 294 (photo files PA160160, 163 and 166 taken over the next 10 minutes) present more of a panoramic view, and document that even the narrow band of surface oil initially blown toward the eastern boom eventually was dispersed. Clearly from these figures, a significant fraction of the oil has been successfully dispersed where it is no longer subject to surface wind or wave-driven transport. Figure 295, Figure 296, and Figure 297 (photo files PA160167, 168 and 169) zero in on the dispersed oil plume as observed from height of 20-25 feet above the water surface, and Figure 298 and Figure 299 (photo files PA160171 and 175) show the accumulation of remaining nondispersed surface oil in the northeast corner of the experimental test zone 23 to 25 minutes into the test. At the same time, the rest of the tank (Figure 300 – photo file PA160176) shows widespread diffusion of the dispersed oil plume throughout the water column. As shown in Figure 299 and Figure 301 (photo files PA160175 and 181), there is some splash over of nondispersed oil into the secondary containment zone 25-28 minutes into the experiment, but it represents only a small fraction of the total oil introduced at the beginning of the test. Figure 302 (photo file PA160188) shows the residual nondispersed surface oil that had accumulated at the northeast corner of the primary containment boom after the wave generator was turned off but before the tank was swept for additional nondispersed oil with the fire monitors. Figure 303 through Figure 306 (photo files PA160192, 195, 198 and 199) show the fire-monitor herding and collection of the nondispersed oil trapped in the northeast corner of the primary test and secondary containment zones at the termination of Test No. 20. Because most of the oil was successfully dispersed in this test, very little oil accumulated along the eastern edge of the containment zone, and what was there was pretty much completely transferred to the northeast corner by the wave train before the termination of the test. Upon collection, it was possible to see how viscous the residual oil that didn't get completely dispersed really is. I estimated that less than 1-2 percent of the non-dispersed oil ended up in the secondary containment zone. As before, all of the oil in the secondary containment zone was included with the rest of the oil collected at the end of the test, and as shown in Table 1, forty seven percent of the spilled oil was recovered yielding a dispersed oil effectiveness value of 53 percent. Based on my visual observations at the time of the test, I would have estimated that the dispersion effectiveness value would have been higher, but this just reinforces to need to monitor dispersant performance by a variety of metrics, including visual scoring, in situ and pumped sample fluorescence, dispersed oil droplet size distributions, and percent nondispersed oil recovered at the end of each test.

The highest fluorometer readings measured in this test were around 24 ppm at the 1-meter depth and around 20 ppm at the 2-meter depth. After getting into clean water at the south end of the wave tank again, the fluorometer values dropped to about 1.8 and 3.6 ppm for the 1- and 2-meter sampling systems, respectively. Therefore, it appears that the flow-through fluorometer approach used for these tests worked very well, and that there was not a lot of residual oil that was trapped or carried over in the pumps and/or tubing systems used to supply the samples to the flow-through cells in the Turner fluorometers housed on the bridge. The fluorometers were recalibrated one more time the following morning with 25, 50, and 100 ppm preparations of dispersed oil in fresh seawater to confirm proper operation throughout the duration of the tests.

Concerns and Conclusions from These Test Observations

Oil Application

After the wave generator has been turned on long enough to establish a steady sea-state (usually 4-6 minutes), the test oil is gently laid down on the water surface as the movable bridge advances to the south (toward the wave generator) at a speed of approximately ½ knot. This is the only practical way to generate a surface slick with generally controllable (and reproducible) surface area dimensions. The oil is not forced into the water column during its initial discharge, and in all of my observations, the oil was on the water surface as it passed under the dispersant spray bar suspended from the back side of the movable bridge. Other than the known (NRC 2005) issue of heating the more viscous oils before application (which has since been corrected with a higher pressure oil delivery and manifold system developed after these tests were completed), I have no concerns about this aspect of the testing protocols.

Dispersant Application

Applying the test dispersant to the oil immediately (within 8-10 seconds) after it is laid down on the water is certainly not representative of the conditions that would be encountered in the field. This approach ensures that the dispersant will hit the target in a reproducible manner (a critical requirement for good testing), but with these viscous fuels, the oil did not have a chance to spread to a uniform thickness before the dispersant was applied. This results in several anomalous (and in some cases competing) factors, that may influence the outcome of the tests. First, because the oil has not spread out on the water surface, a significant fraction of the dispersant misses the oil and is immediately lost to the water column where it no longer has any affect on the oil (NRC 2005). As a result, the oils tested in this program were all "under dosed" (i.e., the oil received far less dispersant than the target or nominal dispersant-to-oil ratio (DOR)), and this can result in lower dispersant effectiveness. On the other hand, because the oil globs and droplets on the water surface were thicker, they may retain or trap the dispersant that does hit them, possibly resulting in better dispersant performance. If dispersant droplets are too large (compared to the surface oil-film thickness) in real-world open-ocean applications, the dispersant may penetrate through the oil film and again be lost to the water resulting in poorer dispersant performance (NRC 1989).

The OHMSETT tests are not designed to evaluate how dispersant droplets land on oil slicks when deployed from helicopters, fixed wing aircraft, or boats (although the tests are close in this regard). Those issues (including whether or not the dispersant even reaches the target) can only be addressed by larger at-sea trials, and because of permitting and liability issues, we are unlikely to see any such tests in U.S. waters any time in the near future. Therefore, researchers are forced to conduct experiments and tests in the best manner possible. At OHMSETT, the application procedure is reproducible (a critical factor in any experimental design), and at least, the OHMSETT protocols use dispersant spray systems that are designed for use in actual oil spill response. In laboratory tests, dispersants are often applied as individual drops from a syringe or micro-pipet to oil slicks that are sometimes no bigger than a quarter (2-3 cm) in diameter, or worse, the dispersant may even be premixed with the oil..

Perhaps during some future series of OHMSETT tests when there is absolutely NO WIND, the investigators could lay down an oil slick according to their standard protocols, allow it to spread out naturally for a minute of two, and then go back and apply the dispersant on a second pass. IF the passing waves don't force this slick out of the target range of the fixed spray boom (or if the dispersant spray boom could be moved from side to side, if necessary), such a test might allow dispersant evaluation on a "more natural" thinner slick. Then, the test could be repeated using the standard protocol where the dispersant is applied immediately after the slick is laid down (as described in this report), and the results compared. Such a comparison may finally put to rest concerns about how the tests can be compared to real world applications. At least, with the protocols utilized at the time of these tests, the researchers were able to accurately measure the oil droplet cross sectional area (and thereby calculate the oil film thickness knowing the volume discharged) to allow a better estimate of the actual dispersant-to-oil ratio (DOR) for each test. No other research group routinely does this.

Finally, while the test protocol of immediately applying the dispersant to the oil right after it is laid down (when it provides the most reproducible target) certainly optimizes the chance for obtaining a good dispersion, it clearly did not do this in many cases when poor or no dispersion was obtained because of a lower applied wave energy or when a poorer performing dispersant was tested. Therefore, while this might be a concern when tests are preformed with fresh, unweathered oil, which will spread out to form a thinner slick, I believe it is less of a concern with evaporatively weathered oil, and it did NOT appear to be an issue with the higher viscosity intermediate fuel oils used in the tests I observed. Quite obviously, the next series of tests that need to be planned should involve higher-viscosity water-in-oil emulsions, which can simulate more weathered oils as they might be encountered at sea. There are numerous practical difficulties with generating and working with such emulsions that will make those experiments difficult to complete, but in my opinion, the OHMSETT facilities are very well suited to approach such a study.

Quantifying Dispersant Performance

After observing all these tests, my biggest concern about using surface collections of residual non-dispersed oil to quantify dispersant effectiveness, is the seemingly consistent 17-26 percent loss in the no-dispersant controls and lower efficiency dispersant studies with poorer performing dispersants and lower wave energies (Test Nos. 10, 11, and 13 – see Table 1). Probable sources of this loss include oil adhesion to the containment booms, “splash over” along the sides of the boom (“splash over” from the end of the tank appears to be adequately addressed with the secondary containment boom), natural dispersion, and collection inefficiencies. On balance, however, I believe that this is a valid approach to conducting these tests in this experimental system, particularly when combined with the numerical ranking of dispersant performance by independent trained observers, subsurface concentration measurements of dispersed oil droplets by fluorometry, and dispersed oil droplet particle size analyses.

There were several instances when the interaction of the boom with the passing wave train introduced additional localized turbulence that clearly enhanced the dispersion of oil that was corralled by the boom in several of the tests. The investigators were quick to recognize this phenomenon and did not include this non-representative dispersion in their numerical scores. It probably did, however, contribute to lower nondispersed, residual surface oil recoveries at the end of several tests and generate percent dispersant efficiency values that were not always in line with the visual observations (e.g., Test Nos. 12, 17, 18, and 19 – see Table 1).

Dispersed Oil Droplet Resurfacing

Extensive oil droplet resurfacing was noted very quickly after one test (i.e., Test No. 12) where only marginal dispersion was noted, and not so much in others (e.g., Test Nos. 15 and 16) where extensive chemically enhanced dispersion was obtained (see Table 1). In Test No. 12, there was significant localized turbulence at the northeast corner of the test area (where all the nondispersed oil was trapped) from the containment boom interacting with the passing wave train, and it is believed that this generated a larger droplet size distribution of dispersed droplets with this otherwise poorly performing dispersant. Within 20-25 minutes of stopping the wave generator at the end of Test No. 12, much of this dispersed oil plume immediately resurfaced. In another instance, nineteen hour after Test No. 18, there was a significant surface slick trapped between the reconfigured boom and the western tank wall, and much of this oil was believed to be from the marginally dispersed IFO 120 fuel oil from Test Nos. 17 and 18 completed the day before. On the other hand, fifteen hours after Test No. 16, there was not near as much evidence of resurfaced dispersed oil despite the very effective dispersions obtained with the IFO 180 fuel oil in Test Nos. 15 and 16. In these two tests, a very light brown (coffee with cream) colored dispersion was obtained, and it was speculated that this might reflect a smaller dispersed oil droplet size distribution.

It should come as no surprise to anyone that most oils are lighter than water, and that if the two are mixed, the phases will eventually separate and the oil can resurface if the mixing energy is taken away. Anyone who has ever shaken a vinegar-and-oil salad dressing should be familiar with this phenomenon. Therefore, when the wave turbulence is removed after a test at OHMSETT (or for that matter, at a much smaller scale in any laboratory test), the dispersed oil droplets will eventually rise to the surface and recoalesce as a slick. The rate of droplet rise is controlled by the oil droplet size, and it is generally held that droplets with a volume median diameter less than 50 μm will remain indefinitely suspended in the water column under conditions of natural open-ocean turbulence (NRC 2005). As such, the droplets are physically advected, dispersed (in the horizontal and vertical), and diluted to the point that droplet collisions and recoalescence are reduced. Then with continued low-level wind and/or wave energy (or even just the turbulence introduced by surface water cooling and sinking), the smaller droplets remain in suspension where they are subject to more rapid oil weathering behavior and eventual microbial degradation (NRC 2005). In this context, it is truly unfortunate that the dispersed oil droplet size data obtained during these studies were never released by Texas A&M University, because they would have provided additional insight on dispersed oil droplet resurfacing behavior and extension of the test results to open ocean conditions. Yes, there is eventual dispersed oil droplet resurfacing at OHMSETT (and in all laboratory tests) because the oil has to go somewhere and it can't escape the tank, but without additional droplet size data, that observation should not be extrapolated to conclude that similar dispersed oil droplet resurfacing will or will not occur at sea. At least at the OHMSETT scale, there is sufficient water volume to simulate the initial diffusion that occurs immediately after chemically-enhanced entrainment, although subsequent advective transport and dilution cannot be evaluated.

Comparisons with At-Sea Trials and Laboratory-Scale Tests

With regard to the specific objective of comparing the OHMSETT tank tests with the at-sea results, Trudel et al. (2005) and SL Ross et al. (2005) found that the tank tests at the intermediate (33.3 cpm) wave energy were most consistent with at-sea results in winds of 11 to 14 knots. The dispersion effectiveness was just slightly higher than that observed at sea, and in tests with Corexit 9500 and both IFO 180 and IFO 380 at 33.3 cpm, the oil viscosity did not limit chemical dispersion in the same way that it had at sea in lower wind speeds. At the lowest wind speeds tested at sea (7 to 10 knots), the limiting oil viscosity in tests with Corexit 9500 lay between the viscosities of IFO 180 (2,075 cP at 16^{o} C) and IFO 380 (7,100 cp at 16^{o} C). At slightly higher wind speeds at sea (11 to 14 knots) dispersant effectiveness was near maximum with both oils, and the effect of oil viscosity was eliminated (Colcomb et al., 2005). OHMSETT tests in 30 cpm waves produced no evidence of chemically enhanced dispersion with any combination of oil, dispersant, and DOR.

The results from four laboratory-scale tests and the SL Ross intermediate scale wave tank were also compared to the OHMSETT studies (SL Ross 2005). Bench-scale laboratory testing included: a) the Swirling Flask Test (the currently promulgated standard test for Environment Canada and the US EPA); b) the Baffled Flask Test (developed by the US EPA to replace the Swirling Flask Test); c) the Exxon Dispersant Effectiveness Test (EXDET); and d) the Warren Spring Laboratory Test (the UK standard). Details are presented in Clark et al. (2005) and SL Ross et al. (2005), but in brief, most of the laboratory tests (and the SL Ross intermediate-scale wave tank) yielded high levels of effectiveness in tests where the combinations of oil, dispersant, and DOR also produced high levels of dispersant effectiveness at OHMSETT and at sea. The exception was the Swirling Flask Test, which produced very low effectiveness results under conditions that produced the highest levels of dispersant performance at sea. None of the laboratory-scale tests replicated the oil viscosity limitation that was observed in the at-sea trials at low wind speeds, but they all showed that IFO 180 was more dispersible than IFO 380. Also, both the OHMSETT and smaller-scale SL Ross wave tanks and most (but not all) of the laboratory bench-scale tests ranked the performance of the dispersant products in the same order as observed at sea.

Hidden Agendas

There are none. SL Ross Environmental Research Limited, Alun Lewis Oil Spill Consultancy, and MMS are doing nothing more than trying to provide an honest assessment of dispersant, oil, and energy combinations to best define the conditions when effective dispersion can be expected. With these tests, their primary objective was to replicate the dispersant testing behavior that was observed during the summer 2003 at-sea trials completed in the United Kingdom. I received full cooperation during my field audit and was allowed free and unfettered access to the entire facility and all data collected during the four days of testing I observed. They are not trying to promote dispersants, but instead provide representative and accurate data that may be useful for making oil-spill response decisions. I saw absolutely no evidence of any bias in numerically scoring dispersant performance above what I thought it should be, and if anything, the investigators were very conservative in not including any anomalous or unrepresentative dispersion (such as that imparted to oil against a boom by localized turbulence from waves interacting with the containment boom) in their numerical scores.

As in any scientific endeavor, methods and protocols are modified and improved as new discoveries are made, and I have every reason to believe that these investigators will continue to make minor changes to the protocols (not to enhance dispersant performance) but to allow accurate testing with a wider variety of oils (e.g., emulsified and weathered oils that are difficult to pump) and under more extreme environmental conditions (e.g., near-freezing and oil in the presence of sea ice, etc.).

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