Impact Modeling Protocol - Kulluk Floating Drilling Platform - Alaska OCS
Tim Martin
to:
Herman Wong
01/20/2011 04:32 PM
Cc:
Natasha Greaves, "'Shell - Susan Childs'", "'Lance Tolson'", Nicole.StAmand, "'Mark Schindler'", "'Schuler, Alan E \(DEC\)'", kirk.lilley, "'Eric Hansen'", "'Kirk Winges'", "'Rodger Steen'", tmartin
Show Details

Herman,

The attached report addresses the proposed impact modeling methods to be used with a permit application that Shell intends to submit to EPA Region 10 in February 2011. This application will be for the drilling of exploratory wells using the Kulluk Floating Drilling Platform in the OCS waters of the Beaufort and Chukchi Seas.

We are mailing four hardcopies of the modeling protocol to EPA Region 10 (two copies for you and two for Natasha Greaves). Please feel free to contact me regarding any additional details.

Regards,

-Tim

Tim Martin
Air Sciences Inc.
111 SW 5th Avenue, Suite 2080
Portland, OR 97204
Phone: 503-525-9394, ext 114
Fax: 503-525-9412
E-mail: tmartin@airsci.com

[redacted] [redacted]

Shell Offshore Inc.
3601 C Street, Suite 1314
Anchorage, AK 99503

January 20, 2011

Mr. Herman Wong
Office of Air, Waste and Toxics
U.S. EPA, Region 10
1200 Sixth Avenue, OAQ-107
Seattle, WA 98101

Re: Impact Modeling Protocol – Kulluk Floating Drilling Platform - Alaska OCS

Dear Mr. Wong:

The attached report addresses the proposed impact modeling methods to be used with a permit application that Shell intends to submit to EPA Region 10 in February 2011. This application will be for the drilling of exploratory wells using the Kulluk Floating Drilling Platform in the OCS waters of the Beaufort and Chukchi Seas. The AERMOD dispersion model, with COARE meteorological data processing to represent dispersion conditions over open water is proposed.

Please feel free to contact Tim Martin (503-525-9394) or me (907-646-7112) regarding any additional details. We appreciate your attention to this protocol.

Sincerely,

Shell Offshore Inc.

Susan Childs
Alaska Venture Support Integrator Manager

Attachment

cc:

Natasha Greaves, EPA R10
Susan Childs, Shell
Lance Tolson, Shell
Nicole StAmand, Shell
Mark Schindler, Octane LLC
Alan Schuler, ADEC, DAQ
Kirk Lilley, attorney
Eric Hansen, ENVIRON Int.
Kirk Winges, ENVIRON Int.
Rodger Steen, Air Sciences Inc.
Tim Martin, Air Sciences Inc.

Shell Alaska Outer Continental Shelf (OCS) Beaufort and Chukchi Seas Exploratory Drilling Program: Kulluk Floating Drilling Platform

Air Quality Impact Modeling Protocol

PREPARED FOR:
SHELL OFFSHORE INC.

In collaboration with ENVIRON International Corp. Lynnwood, WA

PROJECT NO. 180-20-3
JANUARY 20, 2010

CONTENTS

Tables

Figures

Appendices

SECTION 1

INTRODUCTION

Shell Offshore Inc. (Shell) expects to apply for two minor source air permits from the Environmental Protection Agency (EPA) Region 10 (R10) for exploratory drilling using the *Kulluk Floating Drilling Platform (Kulluk)* in the Outer Continental Shelf (OCS) in the Beaufort and Chukchi Seas, Alaska. Shell expects to submit its applications to R10 in February 2011. Shell is submitting this Air Quality Impact Modeling Protocol to EPA as a pre-application measure. This protocol defines the source to be modeled, provides current emissions estimates (final estimates will be provided in the applications), and describes the modeling technique Shell proposes to use in impacts evaluations. This protocol defines the analysis needed for the Beaufort Sea, because, except for the meteorological data set used, the analysis for the Chukchi Sea will be a subset of that required for the Beaufort Sea (the Chukchi Sea leases are much further from shore). A discussion of the meteorological data to be used for both the Beaufort and Chukchi Seas is provided in Appendix B.

A photograph of the *Kulluk*, a Class IV vessel designed for operation in the arctic environment, is provided in Figure 1-1, and lease block locations relevant to this protocol are shown in Figures 1-2 and 1-3. These leases are beyond the Alaska seaward boundary, which is three miles out from the shoreline, and are therefore administered from an air permitting perspective by EPA. However, most of the leases in the Beaufort Sea are within 25 miles of Alaska's seaward boundary, a region within which Alaska air rules must be addressed, in addition to the federal rules that apply throughout the OCS. From an air permitting perspective, only the federal rules apply beyond this 25-mile distance, where some of the Beaufort leases and all the Chukchi leases are located. This modeling protocol addresses all OCS leases currently issued in the Beaufort and Chukchi Seas that are owned by multiple oil and gas companies, including Shell. Inclusion of all leases is necessary because the Kulluk may be subject to agreements between one or more lessees of record where the Kulluk would be used to drill wells on non-Shell leases.

The drilling program is designed so that each season the *Kulluk* has the option to drill several wells or parts of wells, the locations of which are to be determined seasonally as the subsurface resources become better defined. Shell anticipates a maximum drilling season of five months beginning in July, up to 120 days of which the *Kulluk* could be an OCS source. It is likely that environmental conditions (ice and sea states) will limit the time as an OCS source to less than 120 days. At the earliest, drilling is planned to begin in July 2012 and will continue seasonally until the subsurface resources are adequately defined.

Because the *Kulluk* will be an exploratory drilling (NAICS category 211111) source located on the OCS, the applications will be made under the OCS permitting rules (40 CFR 55). Potential emissions from the project will not exceed the 250-ton-per-year Prevention of Significant

Deterioration (PSD) major source review threshold. Thus, the source will be classified as a minor stationary source, and as required in section 55.13(f) of the OCS permitting rules, the source is to be permitting under the 40 CFR Part 71 rules. Because some of the leases in the Beaufort Sea will be within 25 miles from the Alaska seaward boundary region, the section 55.14 corresponding onshore area (COA) rules will apply to operations within this area. The COA rules are contained in Alaska Regulations 18 AAC 50. None of the Chukchi Sea leases are within the 25-mile boundary, so none of the Alaska rules apply to the Chukchi Sea drilling program. Because the *Kulluk* in the Beaufort Sea is considered a portable oil and gas operation by the Alaska Department of Environmental Conservation (ADEC), a minor permit is required per ADEC Regulation 18 AAC 50.502(c)(2)(A). Therefore, for operations outside the 25-mile distance from the Alaska seaward boundary, the Part 71 permitting requirements apply; for operations within the 25-mile distance, both Part 71 and Alaska minor permitting rules apply.

COA requirements for the *Kulluk* drilling in the Beaufort Sea are the ADEC requirements for the Northern Alaska Intrastate Air Quality Control Region (AQCR) 9. This region is designated as attainment or unclassifiable for all criteria pollutants pursuant to 40 CFR 81.302. This area is designated as a PSD Class II Area per 18 AAC 50.015. There are no Class I areas within 300 kilometers of the project location (the nearest Class I area, Denali National Park. is located approximately 700 kilometers to the south of the Beaufort Sea project location); therefore, no Class I impact analyses need to be performed.

As a minor source and for the leases in the Beaufort Sea, the impact components of the federal and Alaska regulations include requirements to address the National Ambient Air Quality Standards (NAAQS) and the additional Alaska Ambient Air Quality Standards (AAAQS) for ambient ammonia and reduced sulfur compounds (RDCs). For the leases in the Chukchi Sea, the impact components only include the NAAQS. This air quality modeling protocol addresses the methods for estimating the impacts from the *Kulluk* and its associated fleet for demonstration of compliance with the NAAQS and AAAQS, which are listed in Table 1-1.

Table 1-1: National and Alaska Ambient Air Quality Standards

	Averaging Time	NAAQS/AAAQS [1] ($\mu g/m^3$)
Nitrogen Dioxide (NO_2)	1-hour [2]	188 (100 ppb)
	Annual	100 (53 ppb)
$PM_{2.5}$	24-hour [3]	35
	Annual	15
PM_{10}	24-hour [4]	150
Sulfur Dioxide (SO_2)	1-hour [5]	196 (75 ppb)
	3-hour [6]	1,300 (0.5 ppm)
	24-hour [6]	365 (0.14 ppm)
	Annual	80 (0.03 ppm)
Carbon Monoxide (CO)	1-hour [6]	40,000 (35 ppm)
	8-hour [6]	10,000 (9 ppm)
Ammonia (NH_3) [7]	8-hour [6]	2,100
Reduced Sulfur Compounds (RDC) [7]	30-minutes	50

[1] National Ambient Air Quality Standards and Alaska Ambient Air Quality Standards.

[2] To attain this standard, the 3-year average of the 98th percentile of the daily maximum 1-hour average must not exceed 100 ppb.

[3] To attain this standard, the 3-year average of the 98th percentile of 24-hour concentrations must not exceed 35 µg/m3.

[4] Not to be exceeded more than once per year on average over 3 years.

[5] To attain this standard, the 3-year average of the 99th percentile of the daily maximum 1-hour average must not exceed 75 ppb.

[6] Not to be exceeded more than once per year.

[7] This standard only applies to the leases in the Beaufort Sea.

Figure 1-1: Kulluk Floating Drilling Platform

Figure 1-2: Beaufort Sea Lease Block Locations

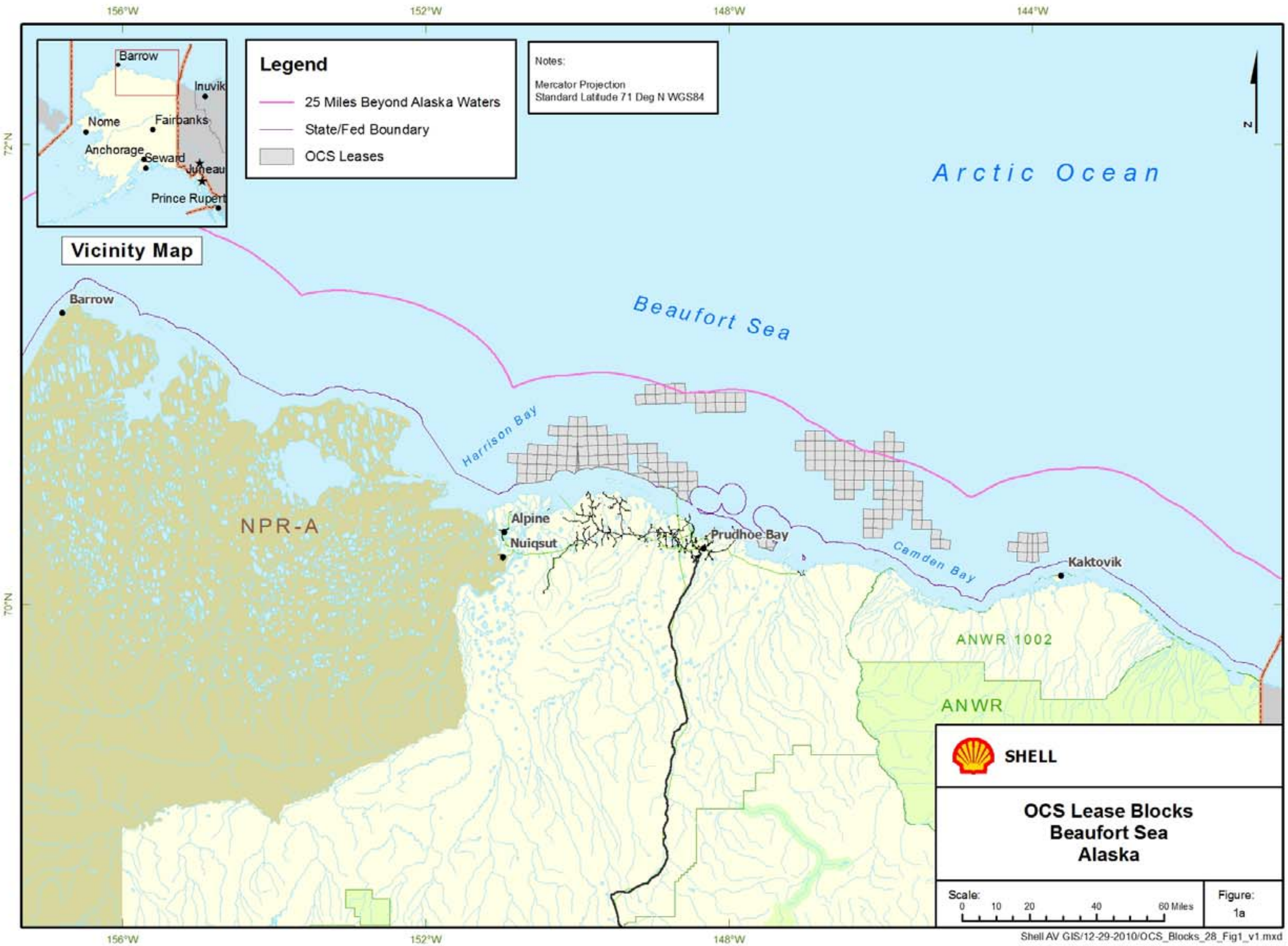
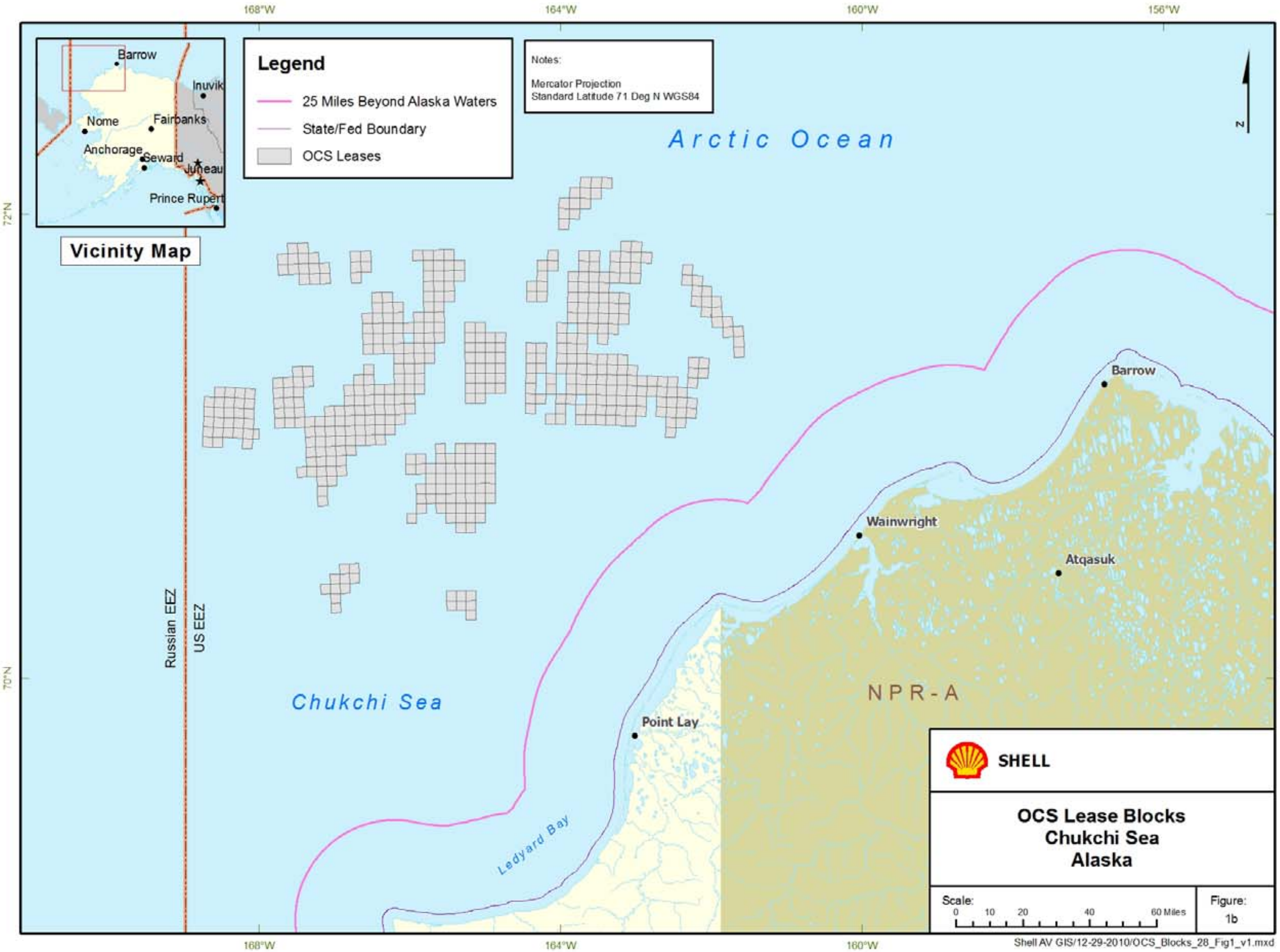


Figure 1-3: Chukchi Sea Lease Block Locations



SECTION 2

PROJECT DESCRIPTION AND DEVELOPMENT OF EMISSIONS

2.1 The OCS Source

The *Kulluk* will be an "OCS Source" under 40 CFR 55.2 when it is attached to the seabed in OCS waters and is being used for exploratory drilling, developing, or producing subsurface resources. Other vessels will become part of the OCS source when they are attached to the *Kulluk*. During drilling, the *Kulluk* will be accompanied by a fleet of associated vessels, which are not considered part of the OCS source. These will include: 1) an anchor handler with the dual purposes of handling the *Kulluk*'s anchors and managing minor ice; 2) a primary ice management vessel; 3) an oil spill response (OSR) vessel carrying and managing smaller work boats; 4) a possible quartering vessel for quartering of personnel; and 5) re-supply vessels. The potential emissions (maximum allowable) from all these vessels, when within 25 miles of the *Kulluk* (and when it is an OCS source), are accounted for in the determination of source category (major or minor), 40 CFR Part 55.13 (d).

The potential emissions from all these vessels will be included in the analysis of possible ambient impacts. For a majority of the time the ice management vessels are expected to be beyond the 25-mile radius of the Kulluk, and for nearly all the time the resupply vessels will be outside the 25-mile radius of the *Kulluk* and will contribute essentially nothing to the ambient impacts around the *Kulluk*. There may be other vessels associated with the drilling project, such as a fuel tanker that will remain at a greater distance than 25 miles from the *Kulluk*, and their emissions will not contribute to either the source categorization or the impacts around the *Kulluk*. Once the *Kulluk* begins drilling and for the entire time it is drilling, the OSR vessel is to be in place near the *Kulluk* to be on call for any unexpected release of oil to the sea surface.

2.2 A Typical Seasonal Drilling Sequence

With the start of each drilling season on or after July 1, the *Kulluk* will be towed into place for the drilling of its first well or part of a well. While held in place by auxiliary vessels, its 12 anchors will be placed on the seabed in a sequence similar to that of tightening tire lug nuts. When all or nearly all the 12 anchors are placed and tensioned, the on-board Shell company representative will declare the *Kulluk* secure and stable, in a position to commence drilling. The reverse sequence will be used to disconnect the *Kulluk* from the seabed. The normal anchoring is performed with the anchor handler backing up to the *Kulluk*, securing and extending the anchor cables out to approximately 800 meters, attaching the anchor, and lowering the anchor into place. Once all or nearly all anchors are placed, they are cinched to engage the anchors in the seabed and remove cable slack. Both anchoring and anchor removal take about two hours per anchor and the entire process can take approximately two days in reasonable weather. Anchoring will not be attempted in rough sea states. The anchors are designed so that in certain events, such as multi-year ice drifting rapidly toward the Kulluk, they can be released from the anchor lines in a matter of minutes, leaving the anchors in place. When the event has passed, the *Kulluk* would return to the site to reconnect and continue drilling. The drilling platform may leave the site for a variety of reasons, including plugging and abandoning (P&A) or temporarily abandoning (T&A) the well, adverse ice conditions, the end of the drill season, or completion of any segment of the drilling of a well.

The drilling process involves three mutually exclusive drilling activities: 1) drilling of the mud-line cellar (MLC), 2) drilling of the well, and 3) casing, logging, and cementing. The *Kulluk* could discontinue drilling after completing the MLC or any of the stages of well drilling and cementing and logging. Once the *Kulluk* finishes its mission at a location, whether drilling to depth or only drilling the MLC, or any other portion of the well, it would raise anchors and either shut down for the season or move to the next drilling location. The drilling locations could be in either the Chukchi or Beaufort Sea and the *Kulluk* could move between them in a single season. From a seasonal perspective, the *Kulluk* could drill as many holes as ice conditions and owner-requested limits (ORLs) would allow. In the best years it is expected to be able to complete a maximum of four wells to depth.

The *Kulluk* will likely need to be resupplied during the season and this could occur while it is an OCS source, or when it is between wells and not an OCS source. For estimation of maximum emissions, Shell assumes a maximum of 24 resupply trips for the 120-day drilling season, an average of one every five days. Resupply involves transiting from outside the 25-mile radius to the *Kulluk*, loading or unloading, and transiting back out of the 25-mile area. The transits are expected to take about three hours and the loading up to a maximum of 24 hours. During this 24-hour period, the resupply vessel would be held in position close to, but not touching, the *Kulluk* in "dynamic positioning" (DP) mode, which means that it will be held in place with its propulsion engines. Resupply could also take the form of a tug bringing a barge to the side of the *Kulluk* and the barge tying up to the *Kulluk* for an extended period of time. That barge will have no sources of emissions on it. As the barge is tied to the *Kulluk*, the tug will move away and outside the 25-mile radius area from the *Kulluk*.

The ice management fleet will only be within 25 miles of the *Kulluk* when there is ice to manage or temporarily for other utility purposes, such as maneuvering an anchor or exchanging workers at the *Kulluk*. These temporary activities would be on the order of an hour in duration, with the vessels in motion most of that time.

2.3 Kulluk Floating Drilling Platform

2.3.1 Kulluk Sources

The *Kulluk* will be equipped with diesel-powered generators to drive the electric drilling motors and other diesel-powered units required for other drilling-related equipment, including hydraulic pumps, cranes, a logging winch, boilers, and emergency-related equipment. This emergency-related equipment includes an emergency generator, lifeboat engines, a hydraulic pump for a remote-operated vehicle (ROV), diver equipment, and possibly other small engines, all of which have highly intermittent use, but will need to be exercised on an infrequent scheduled cycle. The *Kulluk* emissions units are grouped for permitting purposes as source groups of similar engines, each group with a maximum emission limit (lb/day of NOx and $PM_{2.5}$). Since SO_2 is controlled by the fuel quality, its emissions are limited by restricting fuel quality. Carbon monoxide (CO) and volatile organic compounds (VOC) will be low and by specifying NOx and $PM_{2.5}$, the emissions of CO and VOC are implied to a sufficient accuracy to guarantee acceptable impacts. All units are diesel-fuelled. Tables 2-1, 2-2, and 2-3 provide listings of the source groups of the *Kulluk* (and associated fleet, which is discussed later).

As described earlier, the drilling of each well is comprised of three mutually exclusive activities: 1) the drilling of the MLC, 2) the drilling of the well, and 3) logging, cementing, and casing. The MLC (also called a top hole) is a hole about 20 feet in diameter and about 36 feet deep, created to house the well cap and blowout preventer (BOP). Drilling of the MLC involves high use of the primary generators, air compressors, and MLC Hydraulic Power Units (HPU). MLC drilling represents the activity with the highest hourly emissions from all source groups combined. Each MLC is expected to take up to five days per well.

Well drilling is expected to consist of drilling a 36-inch-diameter hole to the required interval and setting 30-inch-diameter steel casing, which is cemented in place to prevent fluid migration through the annular area to the surface. Well drilling activity involves a high use of the primary generators but not the air compressors or HPUs and is the second highest hourly emission activity. The top of the 30-inch casing (bottom of the MLC) has a guide base with receptacles for guidelines that facilitate reentry into the well. The drilling of the well, below the MLC, is expected to take an additional 12 days per well.

Up to an additional 13 days per well can be consumed in the logging, cementing, and casing of the well. These activities can occur intermittently while on location and represent the lowest hourly emission activity scenario. If wells are drilled to depth, Shell anticipates a maximum of four wells per season for a total of 120 days as an OCS source. Although each well is anticipated to consume up to about 30 days and the *Kulluk* would move to another location, for permitting purposes and demonstration of compliance with ambient standards, the platform is assumed to be left at a single well site for the full 120-day season.

Cranes are used intermittently throughout the three drilling activities, although they will be used more during logging, cementing, and casing because of the need to move casing and other equipment into place. There are multiple operational limits on the cranes that keep them from operating at rated power. The boom lifting capacity limits the engines to approximately 60 percent of nameplate power. Normally there will be one crane operated at a time on the *Kulluk.* Moreover, the nature of crane operation is that it lifts or swings only for very short periods (minutes) and idles for long periods of time while being loaded and unloaded. Although infrequent, there may be times that two cranes will operate simultaneously, so Shell will not claim an absolute limit of one crane operating at any one time but accepts a permit condition limiting the use of the cranes to much less than nameplate engine ratings. The boilers are used for heating and only one is intended for use at any time, although the emissions and impacts are estimated assuming that both are operating at nameplate capacity.

2.3.2 Owner Requested Limits (ORLs)

Owner requested limits (ORLs) are enforceable limits placed on an operation for the purpose of limiting its emissions, and in this case they will be used to keep the OCS source categorized as minor and to meet short-term ambient standards. To limit the annual emissions and the frequency of high short-term emissions, Shell anticipates proposing ORLs for the *Kulluk* to limit it to 120 days (2,880 hours) as an OCS source, to 20 days (480 hours) of MLC activity, and 68 days (1,632 hours) of combined MLC and well-drilling activities. Shell also anticipates proposing to limit each source group's emissions. These ORLs are shown on Tables 2-1, 2-2, 2-3, and 2-5. The *Kulluk* incinerator is intended for disposal of non-hazardous domestic and industrial waste. It is to be limited in operation by ORL to 12 hours of use, during the daytime, expected to be 8 a.m. to 8 p.m. During that time it could operate at capacity.

There are multiple emergency and small source units, including life-boat propulsion engines, diver emergency air compressors, and a larger emergency generator. These exist for emergency purposes and are not planned to be used, but they need short and infrequent exercising. Except for the emergency generator, this engine exercising results in very minor emissions from each emission unit, and exercising the individual unit emissions will be spaced throughout a weekly or longer period. In other words, the units will not be exercised simultaneously, but will be relatively evenly spaced over at least a week or longer period of time, and an assumption of an average emission from these sources is reasonable. Shell proposes to account for these seldom-used source emissions through a weekly fuel allocation. To account for the larger monthly two-hour exercising of the emergency generator required by US Coast Guard (USCG) rule, the emergency generator emissions will be modeled as a once-per-30-day occurrence, emitting at engine capacity. These emergency generator emissions will be subtracted from the seldom-used source emissions, which will otherwise be emitted and modeled as an average over time.

The per-source-group emission ORL limits for the three separate activities (MLC drilling, well drilling, logging and cementing) are shown in shading on Tables 2-1 through 2-3. The source group ORLs are in the form of emission maxima per activity, which provides necessary flexibility in use of and types of equipment needed for drilling, while demonstrating compliance with the ambient standards. Shell anticipates possible change-out of engines and alteration of use patterns as maintenance requires and as drilling practices in the Arctic are optimized. There is also a need for flexibility in locations of the ancillary vessels relative to each other and to the *Kulluk* because location is substantially driven by uncertain and varying environmental conditions, such as ice and sea states.

2.3.3 Kulluk Emission Controls

Shell currently anticipates the *Kulluk* to have selective catalytic reduction (SCR) as a NOx tailpipe emission control on its primary generators. From recent stack testing experience with the *Discoverer*, a NOx emission level of 1.0 g/kW-hr is readily attainable and likely to be equal to or above the manufacturer's guarantee. Shell assumes this level of 1.0 g/kW-hr as the maximum for its NOx emission estimates and will demonstrate this through stack testing. The primary generators will also have oxidation catalysts installed for control of all oxidize-able substances, including $PM_{2.5}$, VOC, and CO. A $PM_{2.5}$ emission level of 0.25 g/kW-hr or lower is used as maximum and will be demonstrated by stack test. CO and VOCs are expected to be controlled to 80 percent and 70 percent respectively, as estimated in the EPA emission manual, AP-42. Since there is no risk of exceeding 250 tons of either, or of violating the ambient standards for these two pollutants, no stack test should be necessary to demonstrate these efficiencies.

The other normally used engines in the drilling activities, including the thrusters (which in the anchored state are used to power the air compressors), the MLC HPUs, and cranes, will have oxidation catalysts as tailpipe control for oxidizing all oxidize-able substances, including $PM_{2.5}$, VOC, and CO. Control of engine emissions is assumed to be 50% for $PM_{2.5}$, 80% for CO, and 70% for VOC.

2.3.4 Fuel Quality

Shell will purchase ultra-low-sulfur diesel (ULSD) fuel for use in the *Kulluk* while an OCS source, and also for use in all the associated fleet. This fuel is produced with a sulfur content of 15 ppm sulfur by weight or less. Use of fuel of this quality for marine vessels is practically non-existent and the current infrastructure (delivery piping, barges, etc.) for delivering this fuel is not capable of maintaining the ULSD quality because of contamination from previously loaded fuel with higher levels of sulfur. For this reason, although Shell commits to purchasing ULSD, Shell requests a limit of 100 ppm sulfur in the fuel purchased as ULSD and consumed by the *Kulluk* (and associated fleet).

2.3.5 Estimation of Emissions

Emissions for each source group are estimated using emission unit nameplate outputs, adjusted by system limits and ORLs, then applying appropriate emission factors and tailpipe control efficiencies. These emission factors are taken from existing stack test information or manufacturers' stated emission factors (for the larger sources and NOx and $PM_{2.5}$ pollutants) or from EPA's AP42 manual (for the small sources and pollutants of lower importance). These represent maximum expected emissions and Shell accepts the responsibility of meeting these maximum estimated emissions on a daily basis (weekly for the seldom-used source group). The currently anticipated daily emissions are shown in Tables 2-1, 2-2, and 2-3 and represent the anticipated potentials to emit (PTE) for the source groups. All the assumptions built into the calculation of emissions of all the emission groups are listed on the spreadsheets in Appendix A.

Except for the incinerator, the maximum hourly emissions of all non-emergency sources are calculated as the 24-hour maximum emissions divided equally into 24 hours. This is a reasonable assumption for the *Kulluk* source groups because the 24-hour emissions are also hourly system limits. It may appear that for the cranes there could be higher individual hourly emissions. In fact, since there are three cranes (the total of which Shell considers to be limited to 30 percent of capacity) with normally only one crane operator, only one crane will operate at a time. To even meet the 24-hour maximum emission rate, that one operator would need to operate a crane continuously for nearly the entire day, which is almost impossible. So the 24-hour maximum emission rates are reasonable representations of the hourly maximum rates. The *Kulluk* incinerator is limited by ORL to 12 hours of operation, between 8 a.m. and 8 p.m., and its emissions are calculated at nameplate capacity for those 12 hours.

The seldom-used source group is to be tracked on a weekly basis as discussed above. The emissions from these will be totaled over the week period (168 hours). The only large engine of these seldom-used engines is the emergency generator at 650 kW rating, which is exercised for two hours per month (a USCG requirement). To account for these seldom-used source emissions in the modeling analysis, the emergency generator is run at maximum output for two hours, which consumes 38 gallons per hour per 30-day period, for a total of 77 gallons per 30-day period. Then the remaining allowable emissions, which are from several small engines, possibly including the emergency generator at low loads, running at undefined times, are evenly spread over the 30-day period and will be modeled from the emergency generator stack. The weekly emissions are equal to the total weekly for seldom-used sources minus the weekly component assigned to the once-per-30-day emergency generator exercising (18 gallons per week).

With tailpipe emission controls, there is sometimes a concern with emissions during startup and shutdown. In the case of the *Kulluk* and associated fleet, the anticipated control devices are oxidation catalysts and selective catalytic reduction on the primary generators (and ice management fleet propulsion engines). All these source groups will have started up to some operating level before the *Kulluk* becomes an OCS source and will be operational at some power level throughout the entire time as an OCS source, so startup and shutdown emissions will not be significant from them. It is anticipated that there will be oxidation catalysts on some of the other engines. These catalysts, which are similar to those on automobiles in the United States, warm up quickly in a matter of minutes, so there should be no significant time when these oxidizing control devices are not working. For the *Kulluk* and its fleet, there should be no significant differences in emissions due to startup or shutdown of the sources while the Kulluk is an OCS source.

Table 2-1: Daily Maximum Emissions for Each Source Group – MLC Activity

	NO_X lb/day	PM lb/day	CO lb/day	SO_2 lb/day
Kulluk emission units				
Generation	285.07	71.27	206.35	1.28E+01
MLC HPU'S	887.75	35.51	47.88	2.65E+00
Air compressors	710.20	14.80	42.84	2.65E+00
Cranes	63.92	2.56	3.45	1.91E-01
Heaters & Boilers	21.33	3.52	5.33	1.51E+00
Seldom-used units	10.19	0.82	2.75	3.04E-02
Incinerator	4.97	23.18	496.80	4.14
Ice Management				
Propulsion & Generation	1905.71	317.62	919.63	5.68E+01
Heaters & Boilers	35.56	5.87	8.89	2.52E+00
Seldom-used units	6.79	0.54	1.83	2.03E-02
Incinerator	5.54	25.87	554.40	4.62
Anchor Handler				
Propulsion & Generation	1905.71	317.62	919.63	5.68E+01
Heaters & Boilers	35.56	5.87	8.89	2.52E+00
Seldom-used units	6.79	0.54	1.83	2.03E-02
Incinerator	5.54	25.87	554.40	4.62
Resupply Ship - transport mode				
Propulsion & Generation	0.00	0.00	0.00	0.00E+00
Seldom-used units	0.00	0.00	0.00	0.00E+00
Resupply Ship - DP mode				
Propulsion & Generation	1826.24	76.09	550.80	6.81E+00
Seldom-used units	1.36	0.11	0.37	4.05E-03
OSR vessel				
Propulsion & Generation	1065.30	44.39	321.30	3.97E+00
Seldom-used units	6.79	0.54	1.83	2.03E-02
Incinerator	4.50	21.00	450.00	3.75
Quartering vessel				
Propulsion & Generation	1997.45	16.65	80.33	9.93E+00
Seldom-used units	6.79	0.54	1.83	2.03E-02
Incinerator	4.50	21.00	450.00	3.75
OSR work boats				
Kvichaks	257.45	20.60	69.43	7.68E-01
TOTAL- (lb/day)	**11,061.03**	**1,052.37**	**5,700.78**	**180.95**

shading represents proposed owner requested limit to be demonstrated on a daily basis

shading represents owner requested limit to be demonstrated by on weekly basis

Table 2-2: Daily Maximum Emissions for Each Source Group – Drilling Activity

	NO_X lb/day	PM lb/day	CO lb/day	SO_2 lb/day
Kulluk emission units				
Generation	285.07	71.27	206.35	1.28E+01
MLC HPU'S	0.00	0.00	0.00	0.00E+00
Air compressors	0.00	0.00	0.00	0.00E+00
Cranes	63.92	2.56	3.45	1.91E-01
Heaters & Boilers	21.33	3.52	5.33	1.51E+00
Seldom-used units	10.19	0.82	2.75	3.04E-02
Incinerator	4.97	23.18	496.80	4.14
Ice Management				
Propulsion & Generation	1905.71	317.62	919.63	5.68E+01
Heaters & Boilers	35.56	5.87	8.89	2.52E+00
Seldom-used units	6.79	0.54	1.83	2.03E-02
Incinerator	5.54	25.87	554.40	4.62
Anchor Handler				
Propulsion & Generation	1905.71	317.62	919.63	5.68E+01
Heaters & Boilers	35.56	5.87	8.89	2.52E+00
Seldom-used units	6.79	0.54	1.83	2.03E-02
Incinerator	5.54	25.87	554.40	4.62
Resupply Ship - transport mode				
Propulsion & Generation	0.00	0.00	0.00	0.00E+00
Seldom-used units	0.00	0.00	0.00	0.00E+00
Resupply Ship - DP mode				
Propulsion & Generation	1826.24	76.09	550.80	6.81E+00
Seldom-used units	1.36	0.11	0.37	4.05E-03
OSR vessel				
Propulsion & Generation	1065.30	44.39	321.30	3.97E+00
Seldom-used units	6.79	0.54	1.83	2.03E-02
Incinerator	4.50	21.00	450.00	3.75
Quartering vessel				
Propulsion & Generation	1997.45	16.65	80.33	9.93E+00
Seldom-used units	6.79	0.54	1.83	2.03E-02
Incinerator	4.50	21.00	450.00	3.75
OSR work boats				
Kvichaks	257.45	20.60	69.43	7.68E-01
TOTAL- (lb/day)	**9,463.07**	**1,002.06**	**5,610.06**	**175.66**

shading represents proposed owner requested limit to be demonstrated on a daily basis

shading represents owner requested limit to be demonstrated by on weekly basis

Table 2-3: Daily Maximum Emissions for Each Source Group – Cementing and Logging Activity

	NO_X lb/day	PM lb/day	CO lb/day	SO_2 lb/day
Kulluk emission units				
Generation	201.22	50.31	145.66	9.00E+00
MLC HPU'S	0.00	0.00	0.00	0.00E+00
Air compressors	0.00	0.00	0.00	0.00E+00
Cranes	106.53	4.26	5.75	3.18E-01
Heaters & Boilers	21.33	3.52	5.33	1.51E+00
Seldom-used units	10.19	0.82	2.75	3.04E-02
Incinerator	4.97	23.18	496.80	4.14
Ice Management				
Propulsion & Generation	1905.71	317.62	919.63	5.68E+01
Heaters & Boilers	35.56	5.87	8.89	2.52E+00
Seldom-used units	6.79	0.54	1.83	2.03E-02
Incinerator	5.54	25.87	554.40	4.62
Anchor Handler				
Propulsion & Generation	1905.71	317.62	919.63	5.68E+01
Heaters & Boilers	35.56	5.87	8.89	2.52E+00
Seldom-used units	6.79	0.54	1.83	2.03E-02
Incinerator	5.54	25.87	554.40	4.62
Resupply Ship - transport mode				
Propulsion & Generation	0.00	0.00	0.00	0.00E+00
Seldom-used units	0.00	0.00	0.00	0.00E+00
Resupply Ship - DP mode				
Propulsion & Generation	1826.24	76.09	550.80	6.81E+00
Seldom-used units	1.36	0.11	0.37	4.05E-03
OSR vessel				
Propulsion & Generation	1065.30	44.39	321.30	3.97E+00
Seldom-used units	6.79	0.54	1.83	2.03E-02
Incinerator	4.50	21.00	450.00	3.75
Quartering vessel				
Propulsion & Generation	1997.45	16.65	80.33	9.93E+00
Seldom-used units	6.79	0.54	1.83	2.03E-02
Incinerator	4.50	21.00	450.00	3.75
OSR work boats				
Kvichaks	257.45	20.60	69.43	7.68E-01
TOTAL- (lb/day)	**9,421.84**	**982.81**	**5,551.67**	**172.03**

shading represents proposed owner requested limit to be demonstrated on a daily basis

shading represents owner requested limit to be demonstrated by on weekly basis

Table 2-4: Annual Maximum Emissions for Each Source Group

	NO_X tons/year	PM tons/year	CO tons/year	SO_2 tons/year
Kulluk emission units				
Generation	14.92	3.73	10.80	6.68E-01
MLC HPU'S	8.88	0.36	0.48	2.65E-02
Air compressors	7.10	0.15	0.43	2.65E-02
Cranes	4.94	0.20	0.27	1.47E-02
Heaters & Boilers	1.28	0.21	0.32	9.08E-02
Seldom-used units	0.61	0.05	0.16	1.82E-03
Incinerator	0.30	1.39	29.81	0.25
Ice Management				
Propulsion & Generation	43.45	7.24	20.97	1.30E+00
Heaters & Boilers	0.81	0.13	0.20	5.75E-02
Seldom-used units	0.15	0.01	0.04	4.62E-04
Incinerator	0.13	0.59	12.64	0.11
Anchor Handler				
Propulsion & Generation	43.45	7.24	20.97	1.30E+00
Heaters & Boilers	0.81	0.13	0.20	5.75E-02
Seldom-used units	0.15	0.01	0.04	4.62E-04
Incinerator	0.13	0.59	12.64	0.11
Resupply Ship - transport mode				
Propulsion & Generation	10.96	0.46	3.30	4.09E-02
Seldom-used units	0.08	0.01	0.02	2.43E-04
Resupply Ship - DP mode				
Propulsion & Generation	21.91	0.91	6.61	8.17E-02
Seldom-used units	0.08	0.01	0.02	2.43E-04
OSR vessel				
Propulsion & Generation	38.35	1.60	11.57	1.43E-01
Seldom-used units	0.41	0.03	0.11	1.22E-03
Incinerator	0.27	1.26	27.00	0.23
Quartering vessel				
Propulsion & Generation	71.91	0.60	2.89	3.57E-01
Seldom-used units	0.41	0.03	0.11	1.22E-03
Incinerator	0.27	1.26	27.00	0.23
OSR work boats				
Kvichaks	15.45	1.24	4.17	4.61E-02
TOTAL- (lb/day)	**287.22**	**29.44**	**192.78**	**5.12**

Table 2-5: Proposed Owner-Requested Restrictions

Owner Requested Limit (ORL)	Value
MLC drilling	480 hours per season (20 days)
MLC and well drilling combined	1,632 hours per season (68 days)
All OCS activities combined	2,880 hours per season (120 days)
Number of resupply trips	24 per season
Kulluk incinerator	12 hours per day, 8 a.m. through 8 p.m.
Fuel Sulfur content – Kulluk and Fleet	Purchase ULSD, less than 0.01% during use
All IC engine and heater groups	A set of emission limits (lb/day) for each pollutant, highlighted in Tables 2-1, 2-2, and 2-3.
Annual NOx emissions for Kulluk and Fleet	Less than 250 tpy

2.4 Associated Fleet

While not part of the OCS source, the associated fleet potential emissions are to be used in the determination of source status (major or minor), and the impacts from this fleet are included in the impact analysis. So, its emissions and ORL limits are also addressed. The fleet is to consist of one primary ice management vessel, one anchor handler (also performing minor ice management), one oil spill response (OSR) vessel (which will carry four small work boats on deck), a possible quartering vessel, resupply vessels, and a tanker. The tanker will remain outside a 25-mile radius region from the *Kulluk*, so by rule it will not be included in the determination of source status, and because of distance will not contribute to impacts near the *Kulluk*. Restrictions on use of this fleet, which represent reasonable maximum use for drilling purposes, are taken in the form of ORLs, listed in Table 2-5, with emission rate ORL details included in Tables 2-1, 2-2, and 2-3 to limit the potential emissions.

2.4.1 Ice Management Vessels

The *Kulluk's* associated fleet is to include a primary ice management vessel and a secondary vessel with the combined duties of light ice management and *Kulluk* anchor handling. Ice management involves fragmenting any ice floes that could impact the *Kulluk* and keeping them flowing around the *Kulluk* while it is drilling. Handling of the *Kulluk* anchors involves connecting the anchors to the *Kulluk*, extending the cables out to the anchoring location, and then placing the *Kulluk* anchors on the sea floor. It also performs the reverse process. The frequency and intensity of ice conditions is unpredictable and could range from no ice to ice sufficiently dense that the ice management vessels have insufficient capacity to fragment it. In this extreme case, the *Kulluk* would need to disconnect from its anchors and move off-site. The 2003–2005 statistics on ice at the Sivulliq drill site in the Beaufort Sea show 15 percent frequency of ice at the drill site that would need to be fragmented and a 23 percent frequency of ice not at the drill site, but within 30 miles of the drill site. This statistic was included and further explained in the

Discoverer air permit applications previously submitted to EPA Region 10 ("Outer Continental Shelf Pre-Construction Air Permit Application Revised, Frontier Discoverer Chukchi Sea Exploration Drilling Program," February 23, 2009, and "Outer Continental Shelf Pre-Construction Air Permit Application, Frontier Discoverer Beaufort Sea Exploration Drilling Program," January 2010). A reasonable maximum probability of needing the ice management vessels is considered the sum of these two, which is 38 percent of the drill season.

When ice is present, the management vessels would be somewhere near or up-floe of the *Kulluk* fragmenting the ice. At most other times these two vessels would be beyond the 25-mile radius from the *Kulluk*. For emission estimation purposes the ice management fleet is assumed to be operating at maximum (nameplate rates) rate for 38% of the 120-day OSR period. For modeling purposes, the ice management vessels are assumed to be operating at maximum emission rate whenever the meteorology indicates that ice is present and assumed to be beyond the 25-mile radius when the data indicates open water.

Emission units on the ice management vessels include the propulsion engines and engine-generator sets (generators), heaters, an incinerator, and some seldom-used engines, such as lifeboat propulsion engines and an emergency generator. The vessels can be driven either by direct drive from the diesel or by electric motor from the generators, which in turn are driven by diesel or by a combination. Thus, there can be a mixture of propulsion directly from propulsion engines or by way of generators. Both engine types are large (well over 1000 hp) and usually of the same vintage and therefore have similar emission factors. Thus, the generation and propulsion engines are grouped for emission estimation purposes. Although the seldom-used engines will have a variety of emission factors, their emissions are small relative to the propulsion and generation source group. Therefore, emission factors characteristic of small, higher emitting engines (AP42, Table 3.3-1, small diesel engine emission factors) are used herein. In sum, the ice management vessels have four source groups: propulsion and generation, heaters, an incinerator, and seldom-used engines. The estimated maximum emissions, which are to be taken as ORLs, are shown on Tables 2-1, 2-2, and 2-3. The propulsion engines and generators will have tailpipe emission controls of oxidation catalyst and SCR to limit the emissions of NOx, PM, CO, and VOCs.

Maximum emissions from each source group (except the incinerators) on the ice management vessels are estimated using Shell's estimation of the maximum fuel to be consumed per day for each group multiplied by the emission factors in the form of mass of emissions per unit fuel consumed. For the propulsion and generation and heaters, the maximum fuel consumption assumes engines running at nameplate power level, although normal maximum operating level for propulsion engines is about 85 percent of nameplate rating. For the seldom-used engines the maximum fuel consumption is estimated by Shell from the frequency and time interval of use of these engines, which is less than one percent of the time. These emissions are extremely small and from multiple small engines being exercised for short periods of time that are unrelated to the drilling operation. Without any definition of the times of operation, their emissions will be modeled as averaged over a weekly compliance demonstration period. For the incinerators, maximum daily emissions are the nameplate incineration rate for 24 hours.

2.4.2 OSR Vessel and Quartering Vessels

The OSR vessel will be stationed near the *Kulluk* in preparation for the unlikely event of an oil discharge from the *Kulluk* to the water. It may also serve as a quartering vessel or there may be a separate quartering vessel. These vessels are anchored and only move as may be needed to avoid ice floes or to assist the *Kulluk* in unspecified ways, such as in refueling. The OSR vessel is expected to carry four work boats. These boats are stored on the OSR vessel and enter the water only to move containment booms during cleanup or on-water drill exercises, as a backup for crew changes, and for possible assistance during re-fueling. The OSR fleet will have on-water drills at a maximum frequency of once per day, and up to eight hours for each exercise. The exercise will normally consist of two work boats, towing an open apex boom diverting a water stream back to the OSR vessel. A third work boat could be in the water for shuttling personnel and equipment among the other vessels.

A possible quartering vessel could also be anchored in the vicinity of the *Kulluk*. Emissions from the OSR and quartering vessel, including the work boats, would be from their propulsion and generator engines. These are divided into the source groups of 1) the large vessel propulsion and generation on the OSR and quartering vessels, 2) seldom-used engines on the OSR and quartering vessel, and 3) the work boat propulsion and generation engines. Fuel consumption for each is estimated from the maximum level of activity and engine sizes expected for each source group, and maximum vessel sizes. Emissions are estimated using emission factors available either from stack tests or manufacturer's data. The maximum expected daily emissions are proposed as ORLs, which are shown on the ORL tables above.

2.4.3 Resupply Vessels – Transport and DP Transfers

Although the *Kulluk* will be provisioned at the start of the drilling season, there may be re-provisioning and refueling needs, and the possible need to remove waste materials, while it is an OCS source. Different vessels could be used depending on availability and capability. The re-provisioning and refueling will be by dynamic positioning (DP), where the resupply vessel will hold itself in position a short distance (about 50 feet) from the *Kulluk* hull to the resupply vessel stern hull, using its propulsion systems. Materials will be loaded on and off using one of the *Kulluk* cranes. If waste materials such as drill cuttings are to be transported away from the *Kulluk*, they would be loaded to a barge that would be attached to the *Kulluk*. While attached, that barge would become part of the OCS source, but would have no emission sources on it. The barge would be brought to and removed from the *Kulluk* using a tugboat that would not attach to the *Kulluk*. In this situation the tug would be considered a resupply vessel.

For emission estimation purposes, the resupply vessel is considered to transport supplies from beyond the 25-mile radius of the *Kulluk* to the *Kulluk*, and then it shifts to DP mode for transfer of supplies or fuel. It could be in DP mode for a maximum of 24 hours, and then it shifts back to transport mode and leaves the 25-mile radius area. If the resupply vessel is a tug and barge, the tug and barge would come into the area and the barge would connect to the *Kulluk*, taking much less than 24 hours, and then exit the 25-mile radius. Once the barge was loaded or unloaded, the tug would come back, connect to the barge, and transport it away from the *Kulluk*. For emission estimation purposes, there will be a maximum of 24 resupply (including refueling and waste removal) round trips over the 120-day season (and while Kulluk is an OCS source). Emissions are calculated assuming use of the largest vessel Shell is expected to contract.

There are two mutually exclusive activity modes for the resupply vessel, which are transport to and from the *Kulluk*, and material transfer in DP mode at the *Kulluk*. The first takes about four hours each way and consumes about one-fourth of the fuel consumed in DP mode, which can last a maximum of 24 hours. For daily emission estimates, only the DP mode is considered because it is the larger of the two. DP emissions are estimated with engines operating at a high level needed for the anticipated sea roughness and this operating level must be sufficiently below engine rating to allow for short-term emergencies (including breaking away from DP). This maximum capacity for the 24-hour period is also representative of the shorter-term emissions since the decision to transfer supplies in DP mode is made based on the power required to maintain a position given the roughness of the seas. Sea roughness is driven by synoptic-scale weather patterns, which changes over periods of time greater than 24 hours. For annual emissions, both DP and transit emissions are summed over the ORL limit of 24 trips per season.

There will be one other vessel associated with the OSR fleet, which will be a tanker, residing beyond the 25-mile radius of the *Kulluk*. The tanker's function is to store oil and water from the OSR vessel if it becomes full from cleanup operations. Because of this distance of separation, its emissions will not be counted with the associated fleet potential emissions and its impacts will be negligible near the *Kulluk*. So, its emissions are not included in this analysis.

2.4.4 Associated Vessels Stack Heights as a Function of Power Level

With an unspecified and year-to-year changing fleet such as this, and in particular for the re-supply vessels, which will have a relatively high impact during DP mode, the vessels with highest impact are to be used in the impact analysis. Normally the largest vessels have the largest impact, because they have the highest propulsion power and therefore highest emissions, even though they also have the highest exhaust stacks. This modeling analysis will include a demonstration that the largest vessels of those anticipated for the re-supply will have the highest impact. The analysis will consist of modeling the impacts of the vessel with highest propulsion power and the vessel with lowest propulsion power of the range of vessels for re-supply. From Table 2-6, the Harvey Spirit and Arctic Seal represent the highest and lowest power re-supply vessels. The anticipated emissions and impacts from these two during DP operations will be estimated at distances of 500 meters and further directly downwind.

Table 2-6: Candidate Re-supply Vessels Stack Heights as a Function of Propulsion Power Level

Vessel	Total Propulsion (hp)	Stack ht (m)
Arctic Seal	1,700	8.6
Harvey Spirit	6,140	18.3
Ocean Titan	5,000	10.1
Harvey Explorer	4,520	18.3

2.5 Total Potential Emissions of Kulluk and Associated Fleet Combined

Although the annual emission inventory shown on Table 2-4 shows NOx potential emissions to be 287 tons, this is based on all source groups operating to their maximum and for 120 days. Each year, however, actual total NOx emissions will be well under this value because source use is highly variable depending on the individual well circumstances and the environment, and the combination will never result in all sources operating at maximum for 120 days. To demonstrate this, Shell will track the annual NOx emissions on a weekly rolling annual basis. In the unlikely event the rolling average approached 250 tons of NOx, Shell would shut down the operation for that season. The 287 tons per year emission rate will be used only to demonstrate that at even this rate, which is based on short-term maxima, the annual NOx impacts will be acceptable. Therefore, NOx impacts from emissions under 250 tons per year (tpy) will also be acceptable.

The daily emissions for the associated fleet of all pollutants and all activities are shown in Tables 2-2, 2-3, and 2-4. These tables show that the associated fleet contributes the majority of the NOx emissions (82 percent, 96 percent, and 96 percent for the three activities respectively). For $PM_{2.5}$ the contributions are 86 percent, 90 percent, and 92 percent respectively. The *Kulluk* emissions will be largely independent of the wind conditions, and highest emissions could occur under light winds (poorer dispersion conditions) or strong winds (good dispersion conditions). However, the associated fleet emissions will be highest only under high seas and high winds when the highest power is needed. These are the wind conditions associated with good dispersion conditions. The modeling analysis will assume maximum emissions under all wind and dispersion conditions so the analysis is likely to overestimate the impact of the associated fleet, which has by far the greatest emissions, on the ambient air.

2.6 Emissions as a Function of Load

There are occasional circumstances when impacts from a source are higher at partial load than at full load. The impact analysis will compare load vs. impact for the hourly NOx impact and 24-

hour $PM_{2.5}$ impact from the *Kulluk* generators at two loads, the maximum of which is 85 percent of nameplate rating, and is at the operationally desirable minimum operating level of half (50 percent) of nameplate rating.

SECTION 3

IMPACT EVALUATION METHODOLOGY

The following sections describe the modeling methodologies to be used to determine potential air quality impacts from Shell's OCS Kulluk exploratory drilling operations in the Beaufort and Chukchi Seas.

3.1 Emissions Based on Realistic Source Exclusivity for Purposes of Modeling

As described in Section 2.3.1, there are physical restrictions limiting the use of some emission units concurrently with others. For example, there can be no cementing or logging when there is MLC drilling or well drilling. The HPUs are only used for the drilling of the MLC, normally about a four-day activity per well. Shell proposes to demonstrate compliance under at least three mutually exclusive operating scenarios and for periods of time that are realistic. Shell also proposes to demonstrate compliance with the ancillary vessels at any location, so permits will not have spatial use restrictions.

3.1.1 Proposed Emission Sequencing to Replicate Mutually Exclusive Activities

Shell proposes to account for the mutually exclusive activities in modeling of the maximum impacts in the following way. Assuming four wells per season are to be drilled, the emissions would be sequenced as four wells, each with an estimated 5 days of MLC drilling, followed by an estimated 12 days of drilling of the well, followed by an estimated 13 days of logging, cementing, and casing, which equals a total of 30 days per well and 120 days of activity as an OCS source total per sea. Since MLC drilling activity has higher impacts than either of the two other activities, its duration is limited to 20 days by ORL. If MLCs take place only 10 days, drilling of the well would be allowed for an extra 10 days, for a total of 22 days. Impacts during these additional 10 days would be lower because drilling emissions are the same as MLC except that the air compressors and MLC HPU units would be turned off. Likewise, if MLCs and drilling of the well combined are less than 68 days, then there can be logging, cementing, and casing for more than 52 days per sea-season.

3.1.2 Proposed Emission Sequencing to Replicate Intermittent Activities

Resupply is limited by ORL to a maximum of 24 trips per season. To replicate this intermittent activity for modeling purposes, the resupply vessel emissions in DP mode are turned on for 24 hours every fifth day. The emergency generator on the Kulluk is exercised for two hours every 30 days. To replicate this for modeling purposes, the model will assume that emissions of this generator are turned on to capacity for two hours, applied to the hours of noon to 2 p.m., every 30 days. When the emergency generator is not turned on to capacity for two hours, the emissions from seldom-used sources (several small engines, possibly including the emergency generator at low loads) will occur at undefined times and will be evenly spread over the 30 day period and modeled from the emergency generator stack.

The ice management fleet is to be managing ice only when there is ice present near the drill site. At other times, it is beyond the 25-mile radius of the *Kulluk*. For modeling, ice management will be included when there is ice present near the site as defined by the dispersion meteorological data set (which is also when AERMET is used to process the meteorological data) and will be out of the 25-mile radius when there is no ice (when COARE is used to process the meteorological data). Appendix B provides more information on open-water and ice conditions in the Beaufort and Chukchi Seas.

The Kulluk incinerator is to be limited by ORL to operation within the 12-hour period between 8 a.m. and 8 p.m. The incinerator emissions are turned on and off accordingly in the impact analysis. A table summarizing the operating duration and frequency for the *Kulluk* and associated fleet sources is provided in Table 3-1

In order to eliminate possible bias in the meteorology used for the impact analysis, the hypothetical 120-day emission sequence is modeled with early season meteorology (likely better dispersion), July 1 through October 28, and late-season meteorology (likely worse dispersion and stable ice conditions), August 3 through November 30, and the higher impacts of the two will be taken as representative. The purpose of this is to find the sequence with highest coupled impacts plus background to be compared with the 98^{th} percentile standards for 1-hour NO_2 and 24-hour $PM_{2.5}$ (see Sections 3.8 and 3.9).

3.2 Physical Characterization of the Emission Units

3.2.1 Kulluk

A plan view of the *Kulluk* preliminary source unit configuration is provided in Figure 3-1.

Per EPA's Screening Procedures for Estimating the Air Quality Impact of Stationary Sources, Revised (EPA-454/R-92-019, October 1992) document: sources that emit the same pollutant from several stacks with similar parameters that are within about 100 meters of each other may be analyzed by treating all of the emissions as coming from a single representative stack. Several sources on the *Kulluk* are located next to each other, and merging the stacks for modeling purposes is appropriate because of similarities in source size and location. For these, single-source stack parameters with combined emissions could be used by Shell. If necessary, Shell may also choose not to pursue source co-locations and to explicitly model each individual stack on the *Kulluk*.

.

Table 3-1: Summary of Source Operating Duration and Frequency

Sources	MLC	Drilling	Cementing/ Logging	Operating Duration (hr/day) *	Operating Frequency
	Source Operate During?				
Kulluk					
Generation	Yes	Yes	Yes	24	Every day
MLC HPUs	Yes	No	No	24	Every day
Air Compressors	Yes	No	No	24	Every day
Cranes	Yes	Yes	Yes	24	Every day
Heaters and Boilers	Yes	Yes	Yes	24	Every day
Seldom-Used Units (typical operations)	Yes	Yes	Yes	24	Every day
Seldom-Used Units (emer. gen. exercising)	Yes	No	No	2 (12pm - 2pm)	Every 30 days
Incinerator	Yes	Yes	Yes	12 (8am - 8pm)	Every day
Associated Fleet					
Resupply Ship	Yes	Yes	Yes	24	Every 5 days
Ice Management	Yes	Yes	Yes	24	On days when ice is present

* When the source is operating.

Given the configuration of the stacks and structures on the *Kulluk*, plumes may be down-washed and pulled into the buildings' wake region. For the analysis, the building downwash parameters used in AERMOD will be calculated using the Building Profile Input Program (BPIP) (Version 04274). The building height and location information to be used in the BPIP analysis are also indicated on Figure 3-1.

Although each well is anticipated to consume up to about 30 days and the *Kulluk* may move to another location, for permitting purposes and demonstration of compliance with ambient standards, the platform is assumed to be left at a single well site for the full 120-day season.

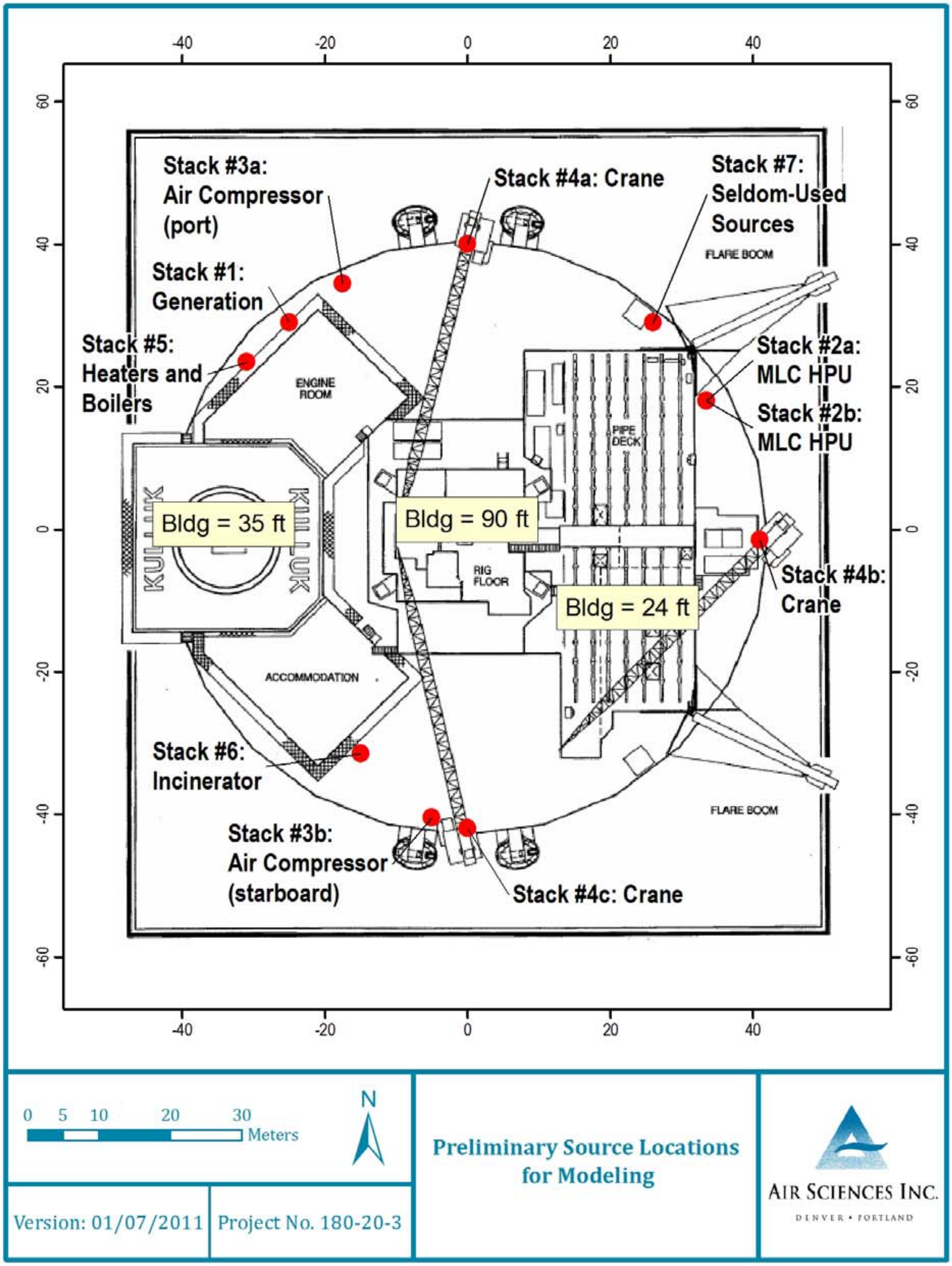
3.2.2 Associated Fleet

With respect to the modeling of impacts from the vessels associated with the *Kulluk*, the ice management/anchor handling vessels, the resupply ship, and the OSR/quartering vessels are all considered to be generic vessels. Emissions from all three are estimated as described in Section 2 and their impacts will be included in the analyses.

The locations of these vessels are on an as-needed basis and changing with winds, environmental conditions, supply needs, training needs, and so on. For ice management purposes, the vessels will generally be within a 5 km radius of the *Kulluk*, but when there is no ice present, which is most of the time, they will be more than 25 miles away. The ice floes are primarily driven by the wind, but sea current also affects the direction of the ice floe, so during ice management the vessels will be generally upwind, but not necessarily directly upwind.

Location of the ice management vessels and associated emissions for modeling purposes during ice management is evaluated based on earlier experience with the *Kulluk. (Full Scale Experience with Kulluk Stationkeeping Operations in Pack Ice [With Reference to Grand Banks Developments] submitted to The National Research Council of Canada [on behalf of PERD Sub-Task 5.3 Oil & Gas] PERD/CHC Report 25-44, B. Wright & Associates Ltd., July 2000, Section 5.5.)* This report provides a thorough explanation of ice management practices, based on experience with the *Kulluk* drilling in the 1980s. Depending on the type of ice, speed, and direction of ice floe, there are different patterns that could be used to fragment the ice so that it can flow around the *Kulluk*. For ice that is not thick, there is intermittent use of the icebreakers, and for fragmenting the ice the vessels would travel at relatively high speed, up to 10 kts (the High Speed Approach) taking about 30 minutes to fragment a typical 1 km x 5 km area up-floe of the *Kulluk*. Then they would stand idle for a period of time. When there is minimal ice motion, the vessels would fragment the ice in the area around the *Kulluk* and then stand idle for the next fragmentation episode. For thicker and moving ice, which is common in the Beaufort, the "Picket Boat Approach" would generally be used. With the Picket Boat Approach the vessels are continually fragmenting at higher power so this approach to ice fragmenting is assumed for purposes of estimating maximum emissions and for defining location of the vessels during periods of maximum emissions for impact modeling purposes.

Figure 3-1: Layout of Emission Units on the Kulluk



With the Picket Boat Approach, the up-flow distance to the nearer ice management vessel is based on the need to be located six hours up-flow, which is the time it would take for the ice fragmented at that location to reach the *Kulluk*. At an average floe speed of 0.15 m/s, the up-flow distance of the nearer vessel would be 3.24 km. The primary vessel would be farther up-flow. No distance is provided for this primary vessel in the study, so it is estimated to be 5 km based on separation distance between vessels for safety purposes. So, for impact modeling purposes, the vessels could range anywhere from the *Kulluk* out to 5 km in ice management activities that consume the higher level of power (assumed to be maximum propulsion power). The "picket" work would be with the secondary vessel that could come near the *Kulluk* to clear around the hull. Thus, the ice management vessel emissions are defined as occurring uniformly throughout a pie-shaped area within a 5 km radius from the *Kulluk*. The width of this area is estimated from Figure 5-4 of the study, and the text to be approximately 40 degrees. The ice management vessels average between 6 and 9 kt (7 to 10 mph) during this mode of ice management activity, so in one hour, each would travel 7 to 10 miles in this 5-km-radius area. This distance represents thorough spreading of emissions across the source pie-shaped area.

The ice management vessels are characterized as area sources, rather than volume sources because the PVMRM code in the regulatory version of AERMOD has known coding errors for volume sources, and because a recent EPA beta version of AERMOD has a limitation regarding the changing of source location on an hourly basis. The current regulatory version of AERMOD has a known error in the PVMRM code which incorrectly overestimates the NO_2 chemistry of point sources when volumes sources are also included in the model runs.

EPA has provided Shell a beta version of the AERMOD code which addresses the PVMRM volume source errors. For selected hours, Shell has verified that the current regulatory version of AERMOD and the beta version of AERMOD produce similar impacts for area sources (i.e., there are no PVMRM code errors in the area source routine of the regulatory version of AERMOD). However, the AERMOD beta code which incorporates code corrections for volume sources with the PVMRM algorithms for evaluation of NO_2 impacts, currently does not allow the changing of source locations hour by hour as is integral to the characterization of the *Kulluk* associated fleet. The largest sources for the *Kulluk* project are the ice management vessels which relocate hourly as a function of wind direction. Thus, an area source configuration of the ice management vessels for the *Kulluk* impact analysis is appropriate both a source characterization standpoint as described above and from a practical standpoint regarding EPA's AERMOD tools which are available for modeling the Shell project.

The anchor handler is also used for handling anchors and bow washing, an activity that requires the vessel to back up to within tens of meters of the Kulluk and turn its propellers to dislodge possible patches of ice frozen to the *Kulluk's* hull. This activity, and that of anchor handling, are near the *Kulluk*, but are at low power, and therefore, low emission levels. The bow washing activity will occur within the pie-shaped areas described above for modeling the ice management vessel emissions.

Unlike the ice management vessels that will be moving continuously when managing ice and within 5 km of the *Kulluk*, the OSR and quartering vessels are expected to be anchored and in a location to the side or downwind of the *Kulluk*, generally in a location where the ice will have been fragmented to flow past the *Kulluk* in the range of 1 to 5 km from the *Kulluk*. In this location there will be essentially no impact contribution on the area surrounding the *Kulluk* where *Kulluk* impacts will be highest. Therefore, the OSR and quartering vessels emissions are ignored in the modeling analysis.

Since the emissions from resupply DP mode are higher than in transit, and since emissions from transit are spread over a large area, the re-supply vessel is modeled in the DP mode. During DP mode, the resupply vessel is stationary, and defined as a point source with a separation distance of 50 feet from *Kulluk* hull (near a *Kulluk* crane) to re-supply vessel stern.

To determine the hourly plume heights as a function of hourly meteorological conditions for the ice management/anchor handler fleet, AERMOD will be used in a two-step process:

1) A line of receptors at several distances downwind from Shell's expected ice management vessel with the lowest stack height will be generated and AERMOD will be run on an hour-by-hour basis, and

2) The results from #1 will be used to determine the receptor with the highest concentration for the given hour for the ice management fleet (in AERMOD's debug file). Then, the plume height at this maximum impact receptor will be used as the initial plume height of the elevated area sources in AERMOD. This approach will couple the worst-case hourly ice management impacts with the *Kulluk* impacts in the full modeling analysis.

These emission heights and area source heights will be calculated on an hour-by-hour basis for use in the impact assessment. The ice management/anchor handler potential emissions will be spread throughout this elevated, pie-shaped area source.

3.3 Model Selection

It is Shell's understanding from verbal discussions at a September 23, 2010 meeting between Shell and EPA that R10 does not object to Shell's use of AERMOD with Plume Volume Molar Ratio Method (PVMRM) chemistry (for NO_2 modeling) and AERMOD without PVMRM chemistry for all other pollutants (e.g., CO, PM, SO_2) using offshore meteorology (e.g., Reindeer Island) to model its OCS sources.

To apply AERMOD at offshore locations, Shell is proposing an approach to attempt to better simulate open-water conditions (compared to running the conventional AERMET meteorological data processor for AERMOD) by using the Reindeer Island tower and buoy data sets (see Section 3.4) to prepare a meteorological data set suitable for AERMOD. This approach would by-pass AERMET during periods when the sea ice has given way to open water and would utilize similarity concepts as described in more detail in Appendix B. The alternative approach by-passes the AERMET meteorological preprocessor using the COARE air-sea flux algorithm[1] and overwater meteorological measurements. R10 has encouraged use of AERMOD with an AERMET-by-pass approach to the meteorological data if the approach does not bias toward underestimations. An analysis of this approach is currently being reviewed by EPA.[2]

For this analysis, the most recent version (09292) of AERMOD will be used to estimate air quality impacts resulting from sources of emissions at the project. AERMOD is an advanced modeling system that incorporates boundary layer theory, turbulence, and effects of terrain features into air dispersion simulations. It is an EPA-recommended guideline model which is appropriate to determine impacts from Shell operations at offshore locations. AERMOD has several technical benefits that are important when modeling impacts from OCS sources that are not available in OCD model.

First, AERMOD directly incorporates the Ozone Limiting Method (OLM) and PVMRM chemistry algorithms in the model code while OCD does not. In order to utilize the PVMRM chemistry, a model with PVMRM directly coded into the model is necessary (e.g., PVMRM cannot be utilized as a post-processing routine). AERMOD is the only Guideline model that incorporates PVMRM.

PVMRM has been judged to provide unbiased estimates of the NO_2/NOx ratio based on criteria that are comparable to, or more rigorous than, evaluations performed for other dispersion models that are judged to be refined, implying unbiased performance.[3] In addition, performance evaluations show that the PVMRM can realistically predict the NO_2 fraction at close-in receptors, yet still provide conservative estimates so that the air quality standards can be protected[4]. PVMRM better simulates the NO to NO_2 conversion chemistry during plume expansion compared to OLM, which uses a simplified approach to the reaction chemistry. In addition, PVMRM is particularly well-suited for the near-field receptor area (also important to Shell OCS modeling), where maximum modeled NOx concentrations are usually predicted.[5]

---

[1] Version 3.0 of the COARE algorithm with journal references can be accessed at: ftp://ftp.etl.noaa.gov/user/cfairall/wcrp_wgsf/computer_programs/cor3_0/

[2] ENVIRON 2010b. *Evaluation of the COARE-AERMOD Alternative Modeling Approach, Support for Simulation of Shell Exploratory Drilling Sources In the Beaufort and Chukchi Seas.* ENVIRON, 19020 33rd Avenue W, Suite 310, Lynnwood, WA 98036; Job No. 0322090, December 16, 2010.

[3] MACTEC, 2005. Evaluation of Bias in AERMOD-PVMRM. Final Report, Alaska DEC Contract No. 18-9010-12. MACTEC Federal Programs, Inc., Research Triangle Park, NC.

[4] Hanrahan, P.L., 1999. The Plume Volume Molar Ratio Method for Determining NO2 / NOX Ratios in Modeling—Part II: Evaluation Studies. *J. Air & Waste Manage. Assoc.*, 49: 1332–1338.

[5] Hanrahan, P.L., 1999. The Plume Volume Molar Ratio Method for Determining NO2 / NOX Ratios in Modeling—Part I: Methodology. *J. Air & Waste Manage. Assoc.*, 49: 1324–1331.

Second, AERMOD contains routines to handle calms or periods of missing data while OCD does not. OCD output files must be post-processed with routines similar to CALMPRO.

Third, EPA is currently incorporating internal routines in AERMOD to calculate the 98th and 99th percentile concentrations necessary for comparisons with the new 1-hour NO_2 and SO_2 ambient standards. These and other future refinements to AERMOD will not be available to OCD unless EPA decides to update and support this model.

Fourth, AERMOD incorporates the updated prime downwash algorithms, which have improved upon the older, more simplistic building downwash scheme included in OCD. Building downwash plays an important role for Shell's OCS sources when calculating impacts at near-field receptors. For prior permitting actions of Shell OCS sources, the prime downwash algorithms (in ISC-PRIME) were utilized for this reason. Thus, there is precedent for using PRIME with OCS permitting. For its continued permitting of similar exploration activities, Shell believes that AERMOD is a relevant option for modeling OCS activities given that the Shell OCS leases are for the most part tens of miles offshore, and the highest impacts from Shell's OCS activities will occur at receptors located near the offshore drilling locations.

Fifth, the environmental condition associated with highest emissions is drilling and simultaneous ice management, which occurs with ice floes and not open water. During this condition, the ice management ships are managing the ice, essentially fragmenting it so that it will flow around the drill vessel, but there is negligible open water nearby the drill vessel. AERMOD is more appropriate than OCD in these surface conditions. During open water circumstances, the ice management fleet is over 25 miles away from the drill ship (to avoid being a part of the OCS source). By focusing the impact analysis on this condition, the highest impacts should be more accurately modeled.

In addition, it is Shell's understanding that EPA Region 4 has previously allowed the use of AERMOD for OCS modeling analyses in the Gulf of Mexico so there is EPA precedence for the use of AERMOD to determine offshore impacts.

3.4 Meteorological Data

3.4.1 Overview of Shell's Meteorological Stations

Shell operates a meteorological collection network in northern Alaska (both the Beaufort and Chukchi Seas and coastal areas) to provide data for modeling applications of both offshore and onshore sources. Shell's meteorological collection effort focuses on both coastal and offshore locations as shown in Figure 3-2. Surface meteorological observations in this region are or will be collected at Badami (or a possible Barter Island/Kaktovik replacement), Reindeer Island and Endeavor Island, Wainwright (with Conoco Phillips), and Point Lay. A buoy was operated near Reindeer Island during the summers of 2009 and 2010. In 2009 and 2010, offshore data were also collected at a buoy operated by Shell Exploration and Production Company (SEPCO) to support exploration activities in the Beaufort and Chukchi Seas. A Beaufort Sea buoy was located near the Sivulliq prospect and a Chukchi Sea buoy was located near the Burger prospect. A thermal profiler has been installed at Endeavor Island to collect data on the boundary layer structure and mixing heights.

As of January 2011, the following reviewed and quality-assured data are available from the following Shell meteorological network for use in dispersion modeling of the Beaufort and Chukchi Sea regions:

Beaufort Sea

- Badami: August 15, 2009 – November 2010 (16 months); data available for 2009 and 2010 drilling seasons
- Reindeer Island tower: April 26, 2009 – November 2010 (19 months); data available for 2009 and 2010 drilling seasons
- Reindeer Island buoy: August 5 – September 3, 2009 (approximately 1 month); and August 18 – September 24, 2010 (approximately 1 month)
- Endeavor Island: May 2010 – November 2010 (7 months)
- Beaufort Sea buoy: August 23 – October 13, 2009 (approximately 1.5 months); and August 13 – October 11, 2010 (approximately 2 months)

Chukchi Sea

- Wainwright: November 2008 – September 2010 (23 months); data available for the entire 2009 drilling season
- Point Lay: June 1, 2010 – November 2010 (6 months)
- Chukchi Sea buoy: September 9 – November 6, 2008 (approximately 2 months); August 28 – September 30 (approximately 1 month); and July 21 – October 20, 2010 (approximately 3 months)

Currently, Reindeer Island is the most complete data set for an offshore location for use in dispersion modeling. Reindeer Island is a small, natural barrier island located in the Beaufort Sea roughly 14 kilometers from the northern Alaska mainland. Endeavor Island is an island built by BP for the Endicott production facility and is located approximately 6 kilometers to the northeast of the mainland. The Beaufort and Chukchi Sea buoys were deployed to support exploration and survey activities. These data sets did not receive the same level of quality control and assurance as the other Shell data sets. Wainwright (Chukchi Sea coast) and Badami (Beaufort Sea coast) are the most complete data sets for onshore locations.

3.4.2 Meteorological Data for Use with AERMOD

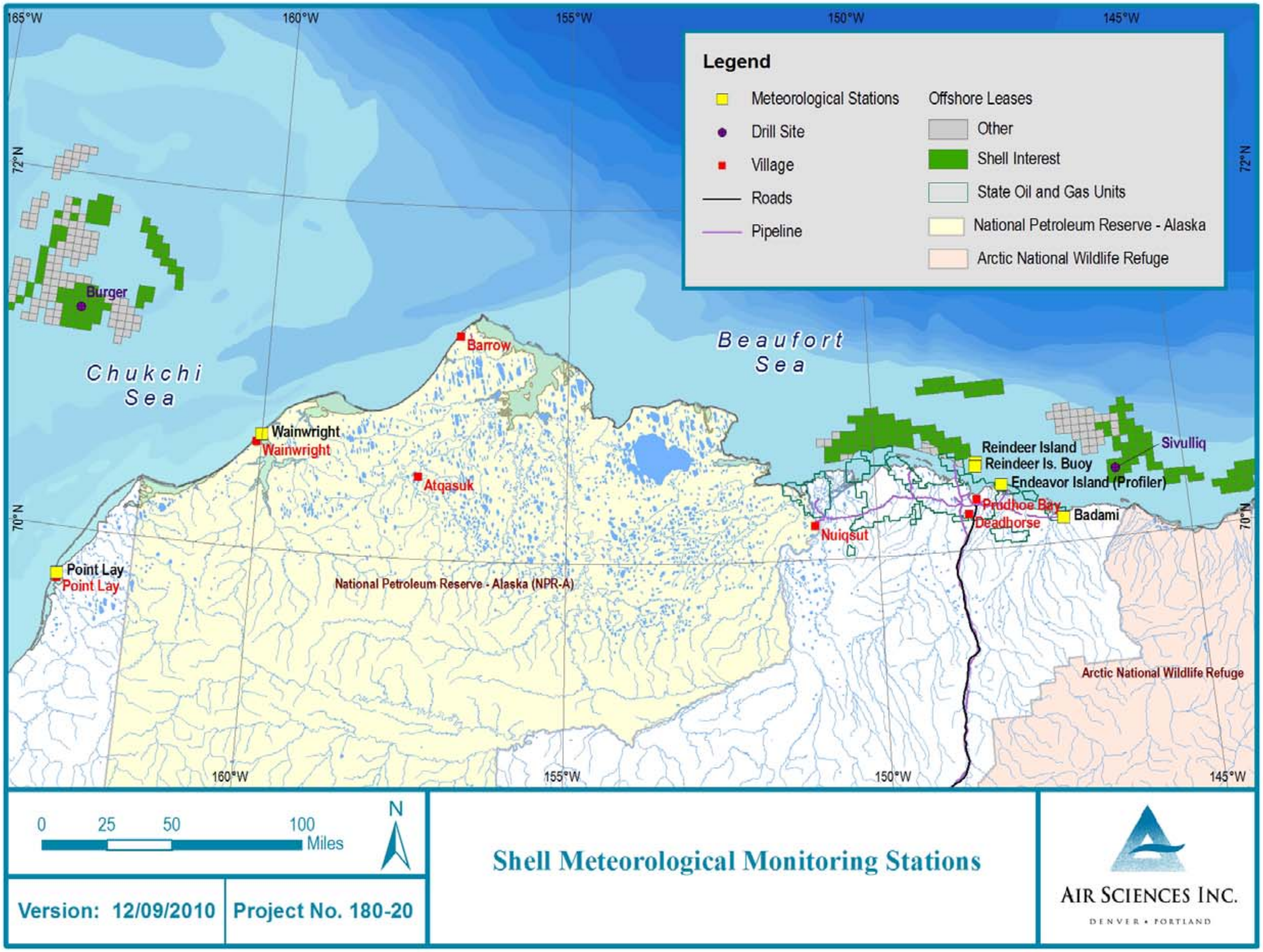
Available data for both 2009 and 2010 will be utilized for the impact analyses of all pollutants (e.g., PM_{10}, $PM_{2.5}$, CO, SO_2), except NO_2. Consistent with EPA's requirement (per the Guideline on Air Quality Models) that permit applicants utilize at least a year of site-specific data, Shell proposes to model *Kulluk* impacts using the most recent and complete year of meteorological (2009), ozone, and NO_2 background data available for the 1-hour NO_2 analyses. Shell does not wish to consider incomplete data sets for 2010 for the 1-hour NO_2 analyses, given the complex forms of the new 1-hour NO_2 NAAQS, which utilize statistics/percentiles based on complete years of data and other data availability issues. Currently, there is no ozone data available in Beaufort Sea region, which are necessary for the 1-hour NO_2 analyses described in Section 3.8. The monitoring organization responsible for the Beaufort Sea ozone station at Barrow (NOAA) has indicated that there is a six-month lag between the dates of ozone data collection and when the data is made available to the public.

The details regarding the preparation of 2009 and 2010 meteorological data for input to AERMOD are complex. Thus, they are provided as Appendix B to this protocol.

3.5 Ambient Air Boundary and Receptors

The ambient air standards are applicable at the ambient air boundary and beyond, which essentially is the nearest location to the *Kulluk* that the hypothetical public can approach. For this analysis, that boundary is established by public safety requirements and protection of the drilling project to be at least 500 meters from the *Kulluk* hull. Within the 500 meter or greater area, Shell must have the unchallenged ability to transfer personnel and supplies, and to manage anchors, ice, and associated fleet vessel operations . This boundary is integral to the drilling operation; Shell cannot drill in the most prudent and safe manner without this zone of protection. Such a zone is consistent with plans approved by the Bureau of Ocean Energy Management, Regulation and Enforcement (BOEMRE). Because this boundary is on the water and there is no physical wall at 500 meters, Shell will prepare an Access Control Plan, which will include locating warning signs at its anchor points and will actively manage the area pursuant to applicable approvals to keep any unidentified vessels away.

Figure 3-2: Map of Shell Meteorological Monitoring Stations in the Beaufort and Chukchi Sea Region



Model receptors will be placed on a 500-meter boundary and spaced at approximately 25 meters around the boundary. To capture maximum impacts from the *Kulluk* and its associated fleet, receptors will be placed every 100 meters out to 1 kilometer from the center of the *Kulluk*. Receptors will be spaced every 250-meters from 1 kilometer to 5 kilometers from the center of the *Kulluk* to cover all activity areas upwind and downwind of the *Kulluk*.

Per EPA R10's request, impact estimates at the nearest villages (at least 50 miles away) to Shell's operations will also be determined.

3.6 Background Concentrations

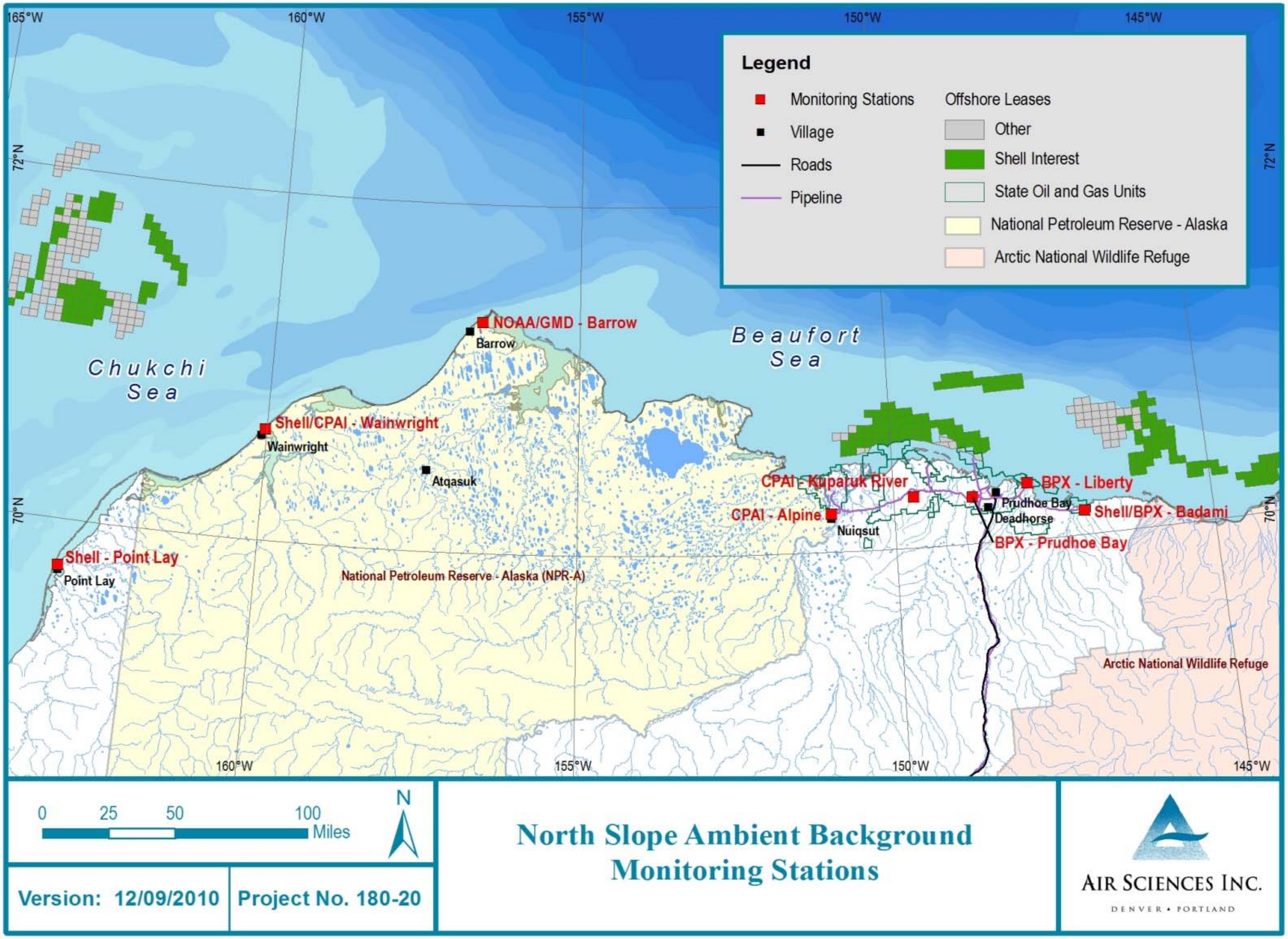
When comparing a project's impact to the NAAQS, an ambient background concentration is needed. The background concentration represents impacts from natural and anthropogenic sources not included in the modeling analysis. EPA's Guideline on Air Quality Models (Appendix W to Part 51, paragraph 8.2.2) identifies two options for isolated sources like the OCS lease block locations addressed herein: 1) collect air quality data in the vicinity of the source, or 2) rely on regional monitoring data.

Ideally, one would locate monitoring stations close to the potential drilling locations, but lack of monitoring sites, safety concerns, hazardous conditions, limited infrastructure/power, and so on, make it infeasible to monitor background concentrations at the Shell OCS lease blocks or even at the nearest shoreline. Given the remote offshore project locations and lack of ambient data from these locations, onsite or near-site data are not available.

According to the Guideline on Air Quality Models (40 CFR 51, Appendix W, Section 8.2.2c), if there are no monitors located in the vicinity of the source, a "regional site" may be used to determine background concentrations. A "regional site" is one that is located away from the area of interest, but is impacted by similar natural and distant man-made sources. Note that as part of the 2009 OCS PSD permits for the *Discoverer* drillship, EPA approved the use of shore-based air quality background measurement for Shell's proposed operations in both the Beaufort and Chukchi Seas. The shore-based monitors are exposed to more natural and man-made sources than would be experienced at OCS sites, so the on-site baseline concentrations would be expected to be lower. The application of onshore data to offshore areas provides a conservative representation of air quality in the area covered by the OCS leases.

Figure 3-3 is a map showing the locations of currently operating and historical ambient monitoring stations on the North Slope.

Figure 3-3: Ambient Monitoring Stations on the North Slope



For the 2009 and 2010 drilling seasons, the following ambient background data shown in Table 3-2 are available and will be utilized to estimate conservative background concentrations at offshore locations in both the Beaufort and Chukchi Seas. For the 1-hour NO_2 analyses, hourly background concentrations will be added to hourly modeled impacts on an hour-by-hour basis to determine a total impact value. For the other ambient standards, (e.g., PM_{10}, $PM_{2.5}$, CO, and SO_2), background concentrations will be added to modeled impacts unpaired in time.

Note that data from the BPX Liberty PSD monitoring program (Endicott Island), the Wainwright station, and other monitors near Prudhoe Bay represent estimates of regional background concentrations for offshore locations in the Beaufort Sea and were approved by EPA for use in the 2009 PSD permits for the *Discoverer* drillship. Shell's Badami monitoring station (previously operated by BPX in 1999) began operating again in August 2009 and provides another data source to estimate offshore background concentrations for the Beaufort Sea region.

The Wainwright and Point Lay monitoring stations provide data sources to estimate background concentrations for the Chukchi Sea region.

Background concentrations to be utilized for the modeling analyses coincide with the drilling season to be permitted (e.g., July through November) and do not include data from the months when Shell OCS drilling will not occur.

3.7 Modeling Approaches

As discussed in Section 1.0, for the leases in the Beaufort Sea, the impact components of the federal and Alaska regulations include requirements to address the NAAQS and the AAAQS (see Table 1-1 above). For the leases in the Chukchi Sea, the impact components only include the NAAQS. Shell anticipates that the most challenging ambient standards will be the 1-hour NO_2 and 24-hour $PM_{2.5}$ NAAQS. More detailed discussions of the proposed modeling approaches for these two pollutants are provided in Sections 3.8 and 3.9 below.

3.8 Modeling Approach for 1-hour NO_2

3.8.1 Overview of EPA Tiered Approach to 1-hour NO_2 Modeling

Currently, the Guideline presents a three-tiered approach converting annual nitrogen oxide (NOx) impacts to annual NO_2 impacts for comparison to the annual NO_2 NAAQS. In a June 28, 2010 EPA memo,[6] the applicability of the Guideline is discussed in the context of modeling for

[6] Fox, Tyler, EPA – Air Quality Modeling Group. [Memo Regional Air Division Directors]. Applicability of Appendix W Modeling Guidance for the 1-hour NO2 National Ambient Air Quality Standard. June 28, 2010.

Table 3-2: Proposed Background Data Sources and Anticipated Use of Background Data

		Beaufort Sea		Chukchi Sea	
Pollutant	Averaging Period	Background Concentration (μg/m³)	Data Source [2]	Background Concentration (μg/m³)	Data Source
NO [2]	1-hour	Varies hourly [1A, 5]	Badami (7/2009 - 11/2009) filled with Prudhoe Bay Pad A when missing	Varies hourly [1A, 5]	Wainwright (7/2009 - 11/2009) filled with Wainwright when missing
	Annual [5]	Varies hourly [1A, 5]	Badami (7/2009 - 11/2009) filled with Prudhoe Bay Pad A when missing	Varies hourly [1A, 5]	Wainwright (7/2009 - 11/2009)
PM_{10} [4]	24-hour	55.1	From Shell *Discoverer* Beaufort Sea PSD Permit Application (Revised September 2009); BPX Prudhoe Bay area (2006, 2007)	114	Maximum at Wainwright (7/2009 - 11/2009 and 7/2010 - 11/2010) and Point Lay (7/2010 - 9/2010)
$PM_{2.5}$	24-hour	Varies daily [1B, 5, *, **]	Badami (8/2009 - 11/2009 and 7/2010 - 11/2010) filled with the two-year average of 98th percentile daily values (7 μg/m³) when missing.	Varies daily [1B, 5, *, **]	Wainwright (7/2009 - 11/2009) and Pt. Lay (7/2010 - 11/2010) filled with the two-year average of the 98th percentile daily values (8 μg/m³) when missing.
	Annual [5]	Varies daily [1B, 5, *, **]	Badami (8/2009 - 11/2009 and 7/2010 - 11/2010) filled with the two-year average of 98th percentile daily values (7 μg/m³) when missing.	Varies daily [1B, 5, *, **]	Wainwright (7/2009 - 11/2009) and Pt. Lay (7/2010 - 11/2010) filled with the two-year average of the 98th percentile daily values (8 μg/m³) when missing.
SO_2 [4]	1-hour	13.0	BPX Liberty (7/2007 - 11/2007) [3]	23.6	Maximum at Wainwright (7/2009 - 11/2009 and 7/2010 - 11/2010) and Point Lay (7/2010 - 11/2010)
	3-hour	11.4		14.1	
	24-hour	4.2		14.1	
	Annual [5]	1.7		0.3	Wainwright (7/2009 - 11/2009)
CO [4]	1-hour	1,746	BPX Liberty (7/2007 - 11/2007) [3]	1,030	Maximum at Wainwright (7/2009 - 11/2009 and 7/2010 - 11/2010) and Point Lay (7/2010 - 11/2010)
	8-hour			1,030	

* Preliminary values subject to change; under review by Shell.

** For the Point Lay 2010 dataset, daily PM concentrations attributable to the Siberian wildfires and blowing dust on July 31 to August 2 are excluded.

[1A] Hourly NO_2 background to be paired with hourly modeled impacts for the 1-hour NO_2 impact analyses.

[1B] Daily $PM_{2.5}$ background to be paired with daily modeled impacts for the 24-hour $PM_{2.5}$ impact analyses.

862

[2] Data from the Exxon Pt. Thompson facility may also be considered if the data is publicly available in the coming months.

[3] This is the same monitoring station utilized for SO_2 and CO background in the Shell *Discoverer* Beaufort Sea PSD Permit (Revised September 2009). The background value presented is the highest concentration representative of the months of Shell's proposed open-water drilling season (July 1 - November 30).

[4] Proposed short-term (i.e., 1-, 3-, 8-, 24-hour) background concentrations for PM_{10}, SO_2, and CO are conservatively assumed as the maximum values measured.

[5] The 120-day period average impacts will be adjested to annual impacts by taking the 120-day average impacts by taking into account the periods of the year when Shell operations don’t occur (i.e., multiply the 120-day average impacts by 0.329 (120 drilling days or of 365 days in year)).

compliance with the new 1-hour NO_2 standard. While the new 1-hour NO_2 NAAQS is defined relative to ambient concentration of NO_2, the majority of NOx emissions for stationary and mobile sources are in the form of nitric oxide (NO) rather than NO_2. Given the role of NOx chemistry in determining ambient impact levels of NO_2 based on modeled NOx emissions, the Guideline recommends a three-tiered approach to modeling NO_2 impacts. According to the June 28, 2010 EPA memo, a summary of EPA's three-tiered approach in respect to the 1-hour NO_2 NAAQS is as follows:

- Tier 1: Total conversion of NO to NO_2 – applies to the 1-hour NO_2 standard without any additional justification,
- Tier 2: Multiply Tier 1 result by empirically-derived NO_2/NOx ratio, with 0.75 as the annual national default ratio – may also apply to the 1-hour NO_2 standard in many cases, but some additional consideration will be needed in relation to an appropriate ambient ratio for peak hourly impacts since the current default ambient ratio is considered to be representative of "area wide quasi-equilibrium conditions," and
- Tier 3: "Detailed screening methods" – will continue to be considered on a case-by-case basis for the 1-hour NO_2 standard.

While the Guideline specifically mentions OLM as a detailed screening method under Tier 3, EPA also considers the PVMRM discussed under Section 5.1.j of the Guideline to be in this category at this time. Both of these options account for ambient conversion of NO to NO_2 in the presence of ozone.

The OLM and PVMRM methods are both available as non-regulatory default options within the EPA-preferred AERMOD dispersion model. As a result of their non-regulatory default status, pursuant to Sections 3.1.2.c, 3.2.2.a, and A.1.a(2) of the Guideline, application of AERMOD with the OLM or PVMRM option is not considered a "preferred model" and can therefore be used, but its use needs to be justified and approved by the EPA Regional Office on a case-by-case basis.

It is Shell's understanding from verbal discussions that R10 does not object to the use of AERMOD with PVMRM chemistry for offshore OCS modeling of 1-hour NO_2 impacts in both the Beaufort and Chukchi Seas. Thus, Shell proposes to use a Tier 3 modeling approach with AERMOD as described below.

3.8.2 Data Necessary to Utilize PVMRM Chemistry

According to EPA, key model inputs for both the OLM and PVMRM options in AERMOD are the in-stack ratios of NO_2/NOx emissions and background ozone concentrations. Shell will have the necessary ambient ozone data (Section 3.8) and in-stack NO_2/NOx ratios to utilize the PVMRM chemistry in a Tier 3 modeling approach. Recognizing the potential importance of the in-stack NO_2/NOx ratio for hourly NO_2 compliance demonstrations, Shell is collecting in-stack ratios from many diesel engines and the incinerator and heaters and boilers that could be used for the 2011

Discoverer drilling program. Engineering judgment will be used to select representative NO_2/NOx ratios for modeling of the sources on the *Kulluk*.

The NO_2/NOx ratios measured from the recent stack testing program for the *Discoverer* drillship diesel engines are provided in Appendix C. For the diesel engines, the average NO_2/NOx ratios for the highest load tests of all sources (i.e., 80-100% load) are 0.117 while the average NO_2/NOx ratios for the lower-moderate load tests (i.e., 50-60% load) are 0.136. The range from all the tests is 0.042 to 0.469. All the tests were performed by the same contractor, which should eliminate contractor-related effects. Tests shown on lines 2 through 8 of the Appendix C results table show high ratios of 0.27 to 0.47, which are for the Caterpillar C15 (a Tier 2 engine) and the Detroit 8V71 engine (a pre-tier engine). There is no similarity of these two engines and furthermore, for a second Detroit 8V71 test, lines 11 through 14 show ratios ranging from 0.05 to 0.26, which are about half the ratios of the line 5 through 8 tests. Neither the Shell engineer on-site during these high ratio tests, nor the testing company, can offer a reason for these high ratios scattered in with many with low ratios. So, the high values are considered anomalous and the average ratio of all the tests (0.117 for high loading and 0.136 for the mid-range loading) will be used for all diesel emissions for the *Kulluk* impact analysis. The average NO_2/NO_x ratio of the available tests for the heaters/boilers is 0.041 and the ratio measured for the incinerator is 0.023 and these values will be used in the *Kulluk* impact analysis for these sources.

3.8.3 Pairing of Modeled Impacts and Background NO_2 Data

In EPA's June 28, 2010 memo regarding 1-hour NO_2 modeling issues, EPA notes that the form of the new 1-hour NO_2 standard has implications regarding appropriate methods for combining modeled ambient concentrations with monitored background concentrations for comparison to the NAAQS in a modeling analysis. EPA recommends that the modeled contribution to the ambient impact assessment for the 1-hour NO_2 standard should follow the form of the standard based on the 98^{th} percentile of the annual distribution of daily maximum 1-hour concentrations averaged across the number of years modeled. A "first tier" assumption that may be applied without further justification is to add the overall highest hourly background NO_2 concentration from a representative monitor to the modeled design value, based on the form of the standard, for comparison to the NAAQS.

EPA allows additional refinements to this "first tier" approach based on some level of temporal pairing of modeled and monitored values to be considered on a case-by-case basis, with adequate justification and documentation. The next two subsections explain Shell's rationale behind why pairing modeled and monitored values is justified and is conservative (i.e., there are no NO_2 sources for offshore in the OCS so use of on-land background values is already very conservative).

Shell believes that temporal pairing of background and modeled values is appropriate from a technical perspective and is consistent with the form of the 1-hour NO_2 standard, and R10 indicated that it was open to this approach in the August 12, 2010 Shell/EPA meeting. The Shell modeling analyses will already have built-in worst-case assumptions, including the use of PTE emissions (rather than actual emissions).

The NO_2 baselines used to pair hourly modeled impacts with hourly background are representative of the regional conditions in Beaufort and Chukchi Seas. The NO_2 data are regional in nature since there are few and only small local sources of NO_2 or hydrocarbons (forming ozone) near the monitoring stations. Also, these on-land measurements are on the high side of representativeness of background concentrations on the OCS because the only sources of these pollutants are on land, nearer to the monitoring stations. Figure 3-4 is a plot of the hourly NO_2 measured at Badami for the proposed 2009 drilling season. Measured NO_2 concentrations at Badami on the Beaufort Sea coast are consistently very low and are only higher than one tenth of the 1-hour NAAQS level (i.e., 19 $\mu g/m^3$) for 11 hours out of more than 3,300 hours measured (i.e., 0.3% of the time). Figure 3-5 is a plot of the hourly NO_2 measured at Wainwright for the proposed 2009 drilling season. Measured NO_2 concentrations at Wainwright are also consistently very low and are only higher than one tenth of the 1-hour NAAQS level (i.e., 19 $\mu g/m^3$) for 40 hours out of approximately 4,350 hours measured (i.e., 0.9% of the time). The few elevated concentration measurements at both monitoring stations are likely the result of impacts from local, shore-based sources. Thus, the use of these higher hourly measurements at locations on the OCS is highly conservative since there are no regional emission sources of NO_2 at the OCS locations.

Figure 3-4: Plot of Measured Hourly NO_2 Concentrations at Badami – 2009 Drilling Season

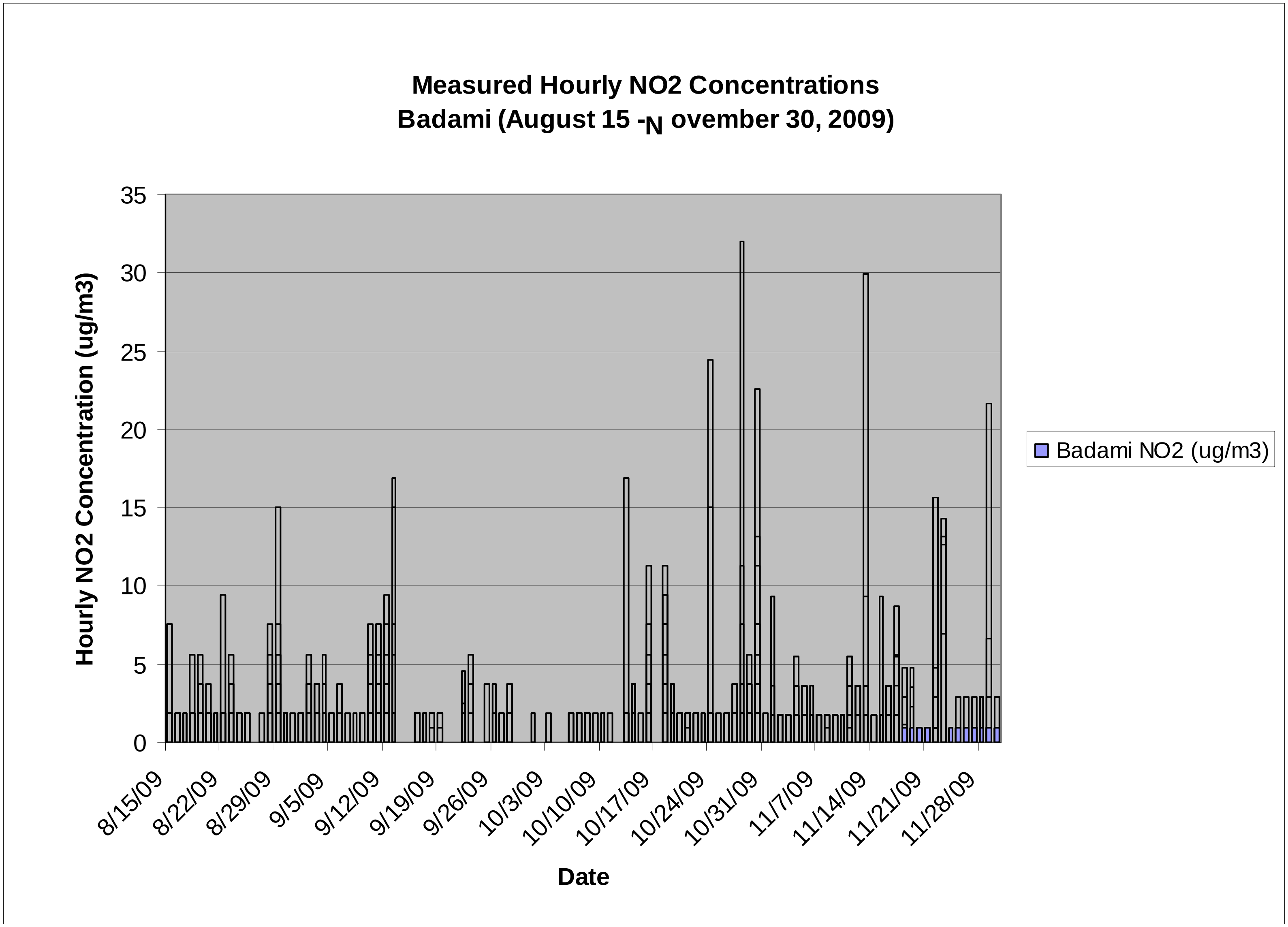
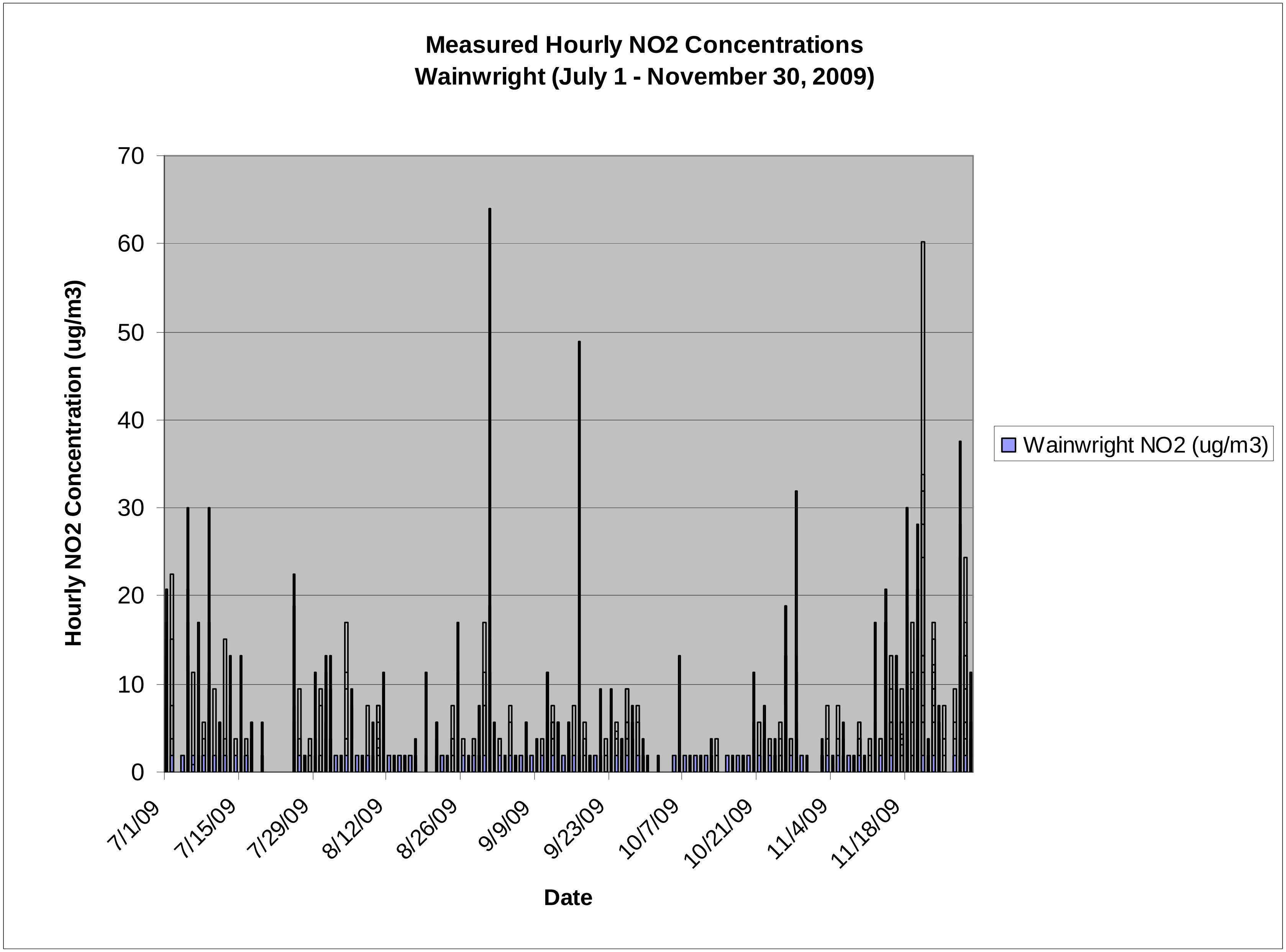


Figure 3-5: Plot of Measured Hourly NO_2 Concentrations at Wainwright – 2009 Drilling Season



EPA R10 Precedent Allowing Use of Shore-Based Measurements at OCS Locations

As part of the recent OCS PSD permit for the *Discoverer* drillship, EPA approved the use of shore-based air quality background measurement for Shell's proposed operations in the Beaufort and Chukchi Seas.

From EPA's statement of basis on the *Discoverer*, Chukchi Sea PSD permit:

> Shell relied on data collected at a monitoring station in Wainwright, Alaska, one of the few locations on the coast of the Chukchi Sea that has even limited infrastructure. There are no islands, platforms or infrastructure in the Chukchi Sea on which to install, operate and maintain ambient air quality monitoring equipment. Wainwright is a rural community on the shores of the Chukchi Sea with a population of around 500. There are a number of air pollution sources in Wainwright, such as a diesel-fired utility electric power plant, a fuel storage facility, airport, residential heating, vehicle exhaust, and unpaved roads. Importantly, Wainwright experiences arctic weather conditions similar to those of the Chukchi Sea. While the Wainwright monitoring station will be somewhat influenced by local sources, EPA believes that it provides a conservative representation of air quality in the area covered by Shell's leases in Lease Area 193 because of the relative closeness of Wainwright to the Shell leases, the relative lack of air pollution sources in Wainwright and the area covered by Shell's leases, and the similarity of the meteorology in Wainwright and the area covered by Shell's leases.

In coordination with EPA, Shell has installed air quality monitoring stations at several shore-based locations that have the necessary infrastructure for air quality monitoring (e.g., Wainwright, Point Lay, Badami), and hourly NO_2 data are measured at each of these stations.

Shell asserts that temporal pairing of hourly modeled NO_2 impacts with hourly background values is an appropriate and conservative technical approach to assessing total modeled impacts. As stated above, EPA has allowed the use of conservative onshore background concentrations to represent offshore locations. Thus, for the Beaufort Sea, Shell proposes to pair hourly modeled NO_2 impacts with hourly onshore background NO_2 (Badami for the Beaufort Sea with Prudhoe Bay area Pad A data when Badami data is missing) to determine a total NO_2 concentration for each hour modeled for the 2009 drilling season. For the Chukchi Sea, Shell proposes to pair hourly NO_2 impacts with hourly onshore background NO_2 from Wainwright for the 2009 drilling season. Then, consistent with the form of the new 1-hour NO_2 NAAQS, the maximum daily 1-hour NO_2 values will be determined, and the 98th percentile of these maximum daily 1-hour impacts will be compared to the 1-hour NO_2 NAAQS.

Data Filling Procedures to Generate Complete Hourly NO_2 and O_3 Data Sets

For NO_2 modeling analyses, both NO_2 and ozone (O_3) data are required. For the Beaufort Sea analyses, hourly ozone concentrations on the North Slope of Alaska (available alternate stations' hour-by-hour values concurrent with the meteorological data) would be evaluated for use in the modeling analyses. For 2009, ozone data are currently available from Barrow and the Prudhoe Bay area (e.g., BP's Pad A station). For the Beaufort Sea NO_2 analyses, hourly NO_2 data from Badami would be used. For the Chukchi Sea modeling analyses, hourly NO_2 and O_3 data available from Wainwright from 2009 would be used. Missing hourly Wainwright ozone data will be filled with hourly ozone data from Barrow to complete the ozone data set for the Chukchi Sea modeling analyses.

To generate a complete NO_2 background data set, the following approach will be taken:

- Beaufort Sea: Use the hourly NO_2 data from Badami when available. If Badami data is missing, fill with Prudhoe Bay area Pad A station. When data from both stations are missing, two hours or less of missing data will be filled by interpolation. When more than two hours of data are missing, fill the missing data with the highest hourly value within 24 hours of the missing hour.

- Chukchi Sea: Use the hourly NO_2 data from Wainwright when available. When Wainwright data are missing, two hours or less of missing data will be filled by interpolation. When more than two hours of data are missing, fill the missing data with the highest hourly value within 24 hours of the missing hour.

3.9 Modeling Approach for $PM_{2.5}$

For modeling of 24-hour $PM_{2.5}$ impacts, Shell proposes to utilize the same models and meteorological data described in Section 3.7 for 1-hour NO_2 impacts, but the modeling of 24-hour $PM_{2.5}$ would not need to include the OLM and PVMRM chemistry methods, which are specific to NO_2 modeling.

As previously mentioned in Section 3.1.1, the highest 24-hour $PM_{2.5}$ impact will be calculated in a similar way to the 1-hour NO_2 impacts where hourly $PM_{2.5}$ impacts will be processed over two 120-day emission sequences and the 98th percentile 24-hour average $PM_{2.5}$ concentration will be determined from the hourly modeled impacts. Similar to the 1-hour NO_2 analyses, which consider paired modeled and background values, the daily 24-hour $PM_{2.5}$ impacts will be paired with the daily $PM_{2.5}$ background concentrations to determine the 98th percentile impacts from the two modeled 120-day sequences. To generate a complete $PM_{2.5}$ background data set, missing days of $PM_{2.5}$ data will be filled with the two-year average 98th percentile of the measured daily $PM_{2.5}$ concentrations (see Table 3-2). For the 2010 Chukchi Sea dataset, missing Point Lay data will first be filled with concurrent Wainwright data. If data from both stations are missing, then missing days of $PM_{2.5}$ data will be filled with the two-year average 98th percentile of the measured daily $PM_{2.5}$ concentrations.

Pairing of Modeled Impacts and Background $PM_{2.5}$ Data

Shell believes that temporal pairing of background and modeled values is appropriate from a technical perspective and is consistent with the form of the 24-hour $PM_{2.5}$ standard. The Shell modeling analyses will already have built-in worst-case assumptions, including the use of PTE emissions (rather than actual emissions). In addition, the Shell source location configurations are already designed to be worst-case.

The $PM_{2.5}$ baselines used to pair daily modeled impacts with daily background are representative of the regional conditions in Beaufort and Chukchi Seas. The $PM_{2.5}$ data are regional in nature since there are few and only small local sources of $PM_{2.5}$ near the monitoring stations. Also, these on-land measurements are on the high side of representativeness of background concentrations on the OCS because the only sources of these pollutants are on land, nearer to the monitoring stations. Figure 3-6 is a plot of the daily $PM_{2.5}$ measured at Badami for the proposed 2010 drilling season. Measured $PM_{2.5}$ concentrations at Badami on the Beaufort Sea coast are consistently very low and are only higher than 20% of the 24-hour NAAQS level (i.e., 5 $\mu g/m^3$) for 3 days out of 139 days measured (i.e., 2% of the time). Figure 3-7 is a plot of the daily $PM_{2.5}$ measured at Point Lay for the proposed 2010 drilling season. Measured $PM_{2.5}$ concentrations at Point Lay are also consistently very low and are only higher than 20% of the 24-hour NAAQS level for 3 days out of 142 days measured (i.e., 2% of the time). The few elevated concentration measurements at both monitoring stations are likely the result of impacts from local, shore-based sources (e.g., fugitive dust). Thus, the use of these higher daily measurements at locations on the OCS is highly conservative since there are no regional emission sources of $PM_{2.5}$ at the OCS locations.

3.10 Modeling Approach for Other Pollutants

For other pollutants with less stringent ambient standards, such as CO, ammonia (Beaufort Sea only) and perhaps SO_2, Shell may pursue a simpler, single modeling run (not separate hourly runs like NO_2 and $PM_{2.5}$), which would be used to calculate impacts. With this modeling approach, the model would internally perform averaging calculations, which would eliminate the setup, post-processing, and EPA review associated with individual hourly model runs used to determine modeled impacts.

Note that lead and reduced sulfur compounds emissions from the *Kulluk* are insignificant and will not be evaluated in the modeling analyses. The only source of sulfur emissions will be from the sulfur in the diesel fuel used on the *Kulluk* and its associated fleets. Because all the fuel is low-sulfur fuel, and the processes using the diesel fuel are oxidation processes, the emissions of reduced sulfur compounds will be negligible and therefore ambient concentrations will also be negligible (same as Shell *Discoverer* PSD permit applications).

Figure 3-6: Plot of Measured Daily $PM_{2.5}$ Concentrations at Badami – 2010 Drilling Season

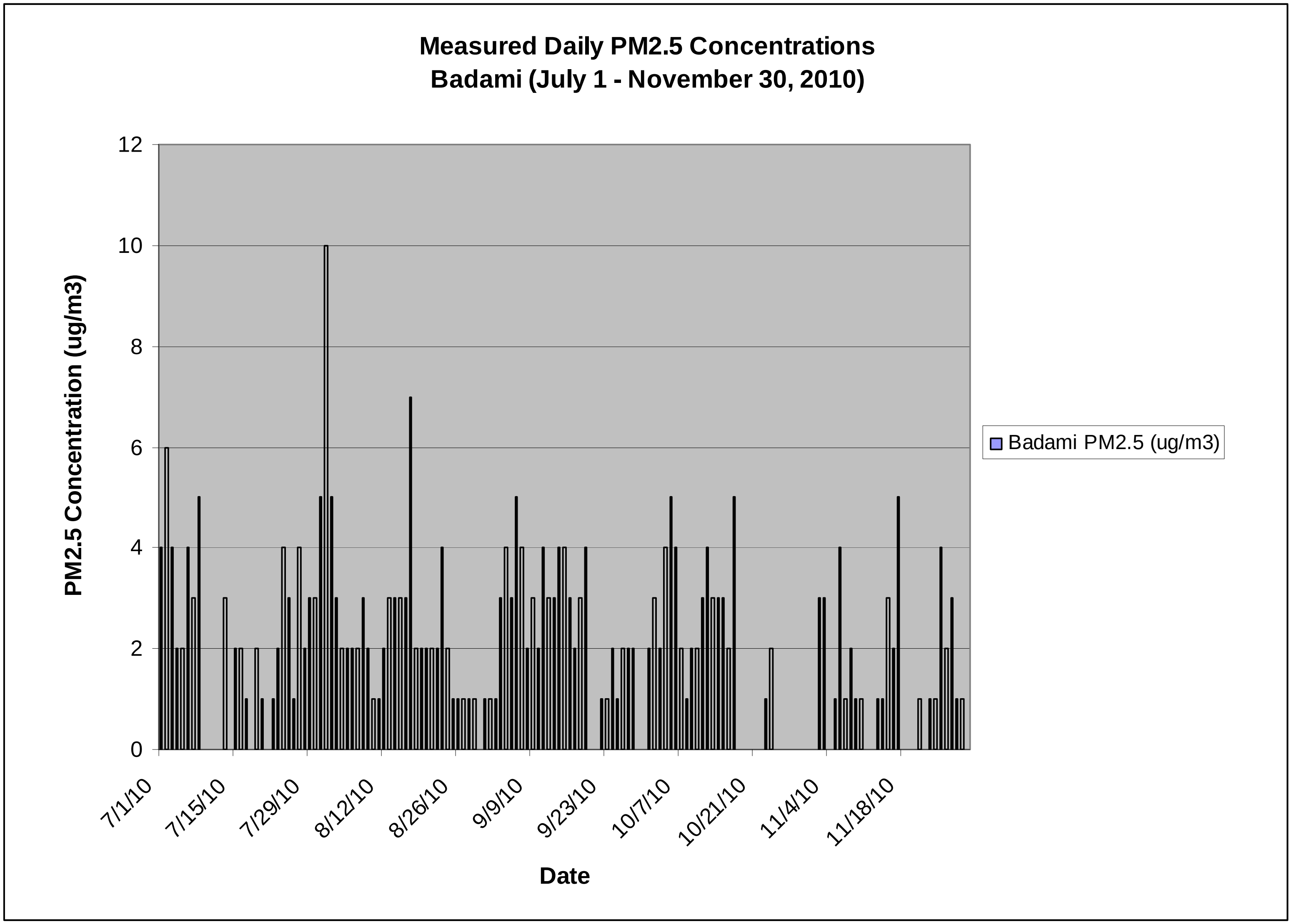
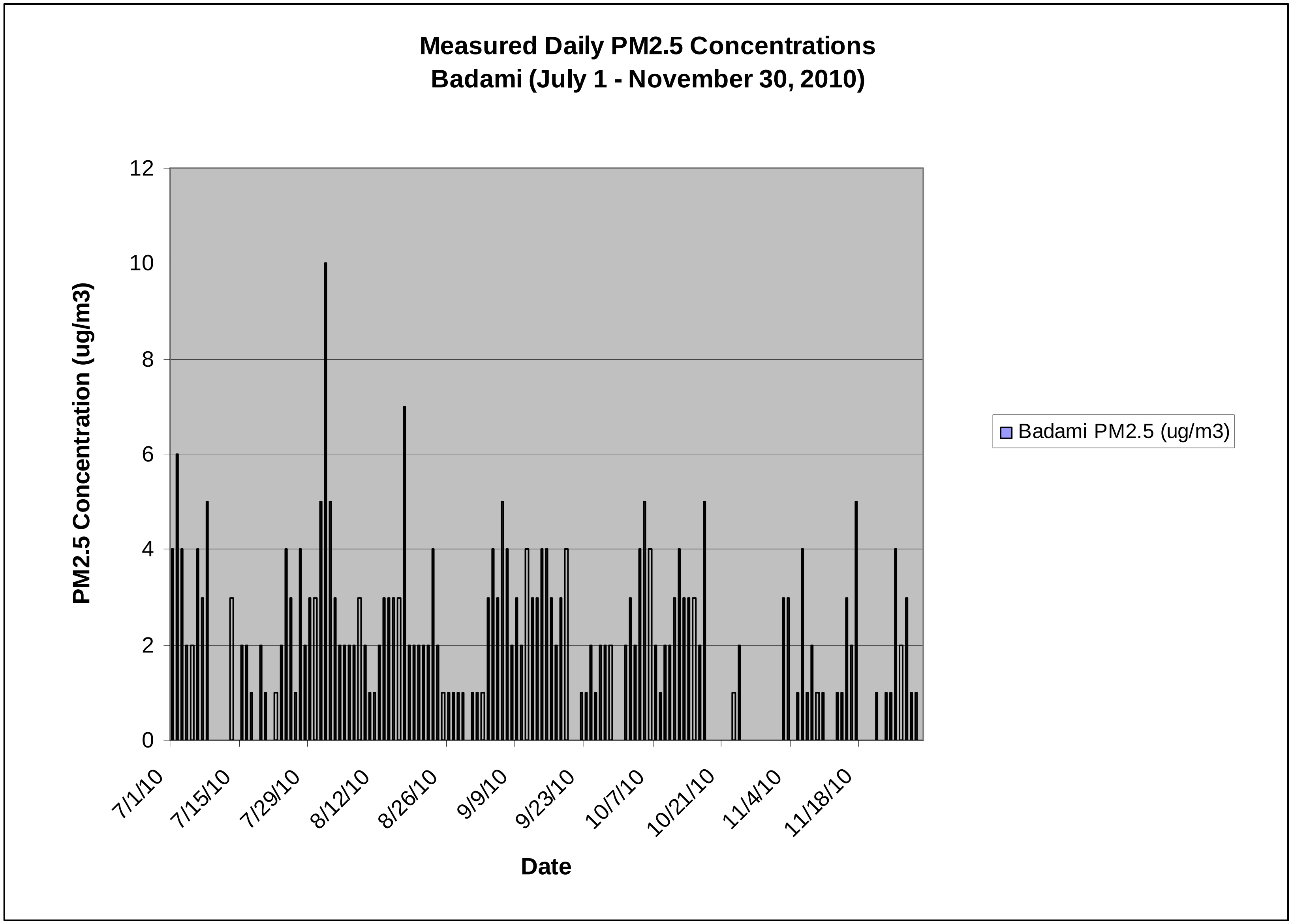


Figure 3-7: Plot of Measured Daily $PM_{2.5}$ Concentrations at Pt. Lay – 2010 Drilling Season



3.11 Modeling Results

The permit application will include a summary of the maximum modeled impacts of the *Kulluk* plus background concentrations for comparison to the NAAQS for the Chukchi Sea analyses and the NAAQS/AAAQS for the Beaufort Sea analyses, along with the receptor location. As part of the modeling submittal, all AERMOD, AERMAP, and BPIP input and output files will be provided electronically.

APPENDIX A

Spreadsheet of Source Usage and Emissions Estimation

shading represents owner requested limit to be demonstrated by documentation of each event
shading represents owner requested limit to be demonstrated by documentation of daily fuel consumption
shading represents owner requested limit to be demonstrated by documentation of weekly fuel consumption

Anticipated Kulluk Operating Maximums

Kulluk & Associated Fleet

Expected Operating Maximums	Limit		How Defined	How documented
MLC Drilling Activity	480	hrs/activity	20 days/activity	
Well Drilling Activity	1,152	hrs/activity	48 days/activity	
Cementing/Logging Activity	1,248	hrs/activity	52 days/activity	
Season maximum drilling duration as an OCS source (secure and stable for commencement of exploratory activity):	2,880	hrs/season	120 days/season	
Ice mgmt vessel use within 25 miles	38%			
OSR vessel annual fuel limit	60%	of daily maximum - annualized		
Quartering vessel annual fuel limit	60%	of daily maximum - annualized		
MLC Activity				
Generators (three units combined) combined	85%	capacity	System Limitation	
Crane (three units combined) maximum	40%	capacity	System Limitation	
Crane (three units combined) maximum	30%	of time (day)	Demo by crane-use study	
Well Drilling Activity				
Generators (three units combined) combined production maximum	85%	capacity	System Limitation	
Crane (three units combined) maximum	40%	capacity	System Limitation	
Crane (three units combined) maximum	30%	of time (day)	Demo by crane-use study	
Cementing/Logging Activity				
Generators (three units combined) combined	60%	capacity	Shell ORL	
Crane (three units combined) maximum	40%	capacity	System Limitation	
Crane (three units combined) maximum	50%	of time (day)	Demo by crane-use study	
All Activities - ORL				
Kulluk Incinerator limited to	12	hr/day	Shell ORL	manual - recording of time start and time stop
Sulfur content of all stationary source engines on Kulluk	0.0100%	by wt.	Shell ORL	Kulluk fuel testing
Sulfur content of associated fleet	0.0100%	by wt.	Shell ORL	Fleet fuel
Annual NOx emissions recalculated as weekly rolling avg	250	ton/yr.	Shell ORL	
Ice Management Fleet Propulsion & Generation	100%	capacity	System Limitation	
Resupply ship in transit limited to:	1,200	gal/1-way	Shell ORL	fuel consumption measurement
Resupply ship in DP mode limited to:	4,800	gal/event	Shell ORL	fuel consumption measurement
Resupply ship resupply events limited to	24	rnd trip/season	Shell ORL	manual tracking
OSR Vessel p & g aggregate power:	2,600	kW		mfgr specifications
OSR Vessel p & g aggregate consumption:	2,800	gal/day	Shell ORL	fuel consumption measurement
Quartering vessel p & g aggregate power:	7,502	kW	Shell ORL	mfgr specifications
Quartering vessel p & g aggregate consumption:	7,000	gal/day	Shell ORL	fuel consumption measurement
OSR work boats	3,789	gallons/wk.	Shell ORL	fuel consumption measurement

OSR Boat Options

OSR vessel: Pt. Oliktuk/Arctic Endeavor

Quartering vessel: Nanuq

Kvichak Work Boats

#1 OSR 34-foot	32	gal/hr
#2 OSR 34-foot	32	gal/hr
#1 OSR 47-foot	63	gal/hr
ALL	6	hr/day
ALL	5	day/week
ALL	100%	hourly fuel consumption

Diesel Engine Thermal Efficiency Assumptions

		Reference
7.1	lb/gal	AP42 Table 3.4-1; footnote a
7,000	Btu/hp-hr	<600 hp; AP42 Table 3.3-1 Footnote (a) ver. 10/96. >600 hp, AP42 Table 3.4-1 ver. 10/96

Conversions

0.1350	MMBtu/gallon
0.7457	kW / hp
1,000,000	Btu/MMBtu
453.6	g/lb
2,000	lb/ton
24	hr/day
168	hr/wk
2	one-way trips/ round trip
32.07	wt S
64.06	wt. SO2
2.00	wt. conversion of S to SO2

** seldom-used engines are those running < 4 hr/wk.

Anticipated Kulluk Operating Maximums

Kulluk & Associated Fleet (continued)

Expected Operating Maximums	Controls NOx	Controls PM	Controls CO	Controls VOC	EF Reference NOx	EF Reference PM	EF Reference CO	EF Reference VOC
Kulluk emission units								
Generation	Kulluk-SCR	OxyCat-Lg	OxyCat-Lg	OxyCat-Lg	4	7	7	7
MLC HPU'S	None-Sm	OxyCat-Sm	OxyCat-Sm	OxyCat-Sm	2	8	8	8
Air compressors	None-Lg	OxyCat-Lg	OxyCat-Lg	OxyCat-Lg	1	7	7	7
Cranes	None-Sm	OxyCat-Sm	OxyCat-Sm	OxyCat-Sm	2	8	8	8
Heaters & Boilers	heat&boil	heat&boil	heat&boil	heat&boil	3	3	3	3
Seldom-used units	None-Sm	None-Sm	None-Sm	None-Sm	2	2	2	2
Ice Management								
Propulsion & Generation	SCR	OxyCat-Lg	OxyCat-Lg	OxyCat-Lg	5	7	7	7
Heaters & Boilers	heat&boil	heat&boil	heat&boil	heat&boil	3	3	3	3
Seldom-used units	None-Sm	None-Sm	None-Sm	None-Sm	2	2	2	2
Anchor Handler								
Propulsion & Generation	SCR	OxyCat-Lg	OxyCat-Lg	OxyCat-Lg	5	7	7	7
Heaters & Boilers	heat&boil	heat&boil	heat&boil	heat&boil	3	3	3	3
Seldom-used units	None-Sm	None-Sm	None-Sm	None-Sm	2	2	2	2
Resupply Ship - transport mode								
Propulsion & Generation	None-Lg	None-Lg	None-Lg	None-Lg	1	1	1	1
Seldom-used units	None-Sm	None-Sm	None-Sm	None-Sm	2	2	2	2
Resupply Ship - DP mode								
Propulsion & Generation	None-Lg	None-Lg	None-Lg	None-Lg	1	1	1	1
Seldom-used units	None-Sm	None-Sm	None-Sm	None-Sm	2	2	2	2
OSR vessel								
Propulsion & Generation	None-Lg	None-Lg	None-Lg	None-Lg	1	1	1	1
Seldom-used units	None-Sm	None-Sm	None-Sm	None-Sm	2	2	2	2
Quartering vessel								
Propulsion & Generation	Nanuq	CDPF-Lg	CDPF-Lg	CDPF-Lg	9	10	10	10
Seldom-used units	None-Sm	None-Sm	None-Sm	None-Sm	2	2	2	2
OSR work boats								
Kvichaks	None-Sm	None-Sm	None-Sm	None-Sm	2	2	2	2

Assumed Control Device Effectiveness	Restriction	Comment	Reference
Oxidation Catalyst CO reduction efficiency	80%	50-100% of capacity	D.E.C. Marine AB letter, October 9, 2008, and initial stack test
Oxidation Catalyst VOC, HAPs (except metals), Formaldehyde reduction efficiency	70%	50-100% of capacity	D.E.C. Marine AB letter, October 9, 2008
Oxidation Catalyst PM reduction efficiency	50%		D.E.C. Marine AB email, February 9, 2009
CDPF reduction efficiency CO, VOC, HAPs	90%		CleanAIR CDPF guarantee
CDPF reduction efficiency PM	85%		CARB Currently verified, Jan. 2009, CleanAIR Systems PERMIT
Kulluk Generator SCR NOx control	1.0 g/kW-hr	50-100% of capacity	June 2010 Discoverer Stack Testing

Engine	NOx		CO		VOC		PM*		
Emission Factors / Controls	g/kW-hr	lb/gal	lb/MMBtu	lb/gal	lb/MMBtu	lb/gal	g/kWhr	lb/gal	
None-Lg	12	0.3805	0.85	0.1148	0.09	0.0122	0.50	0.015853	1
None-Sm	15	0.4756	0.95	0.1283	0.35	0.0473	1.20	0.038047	2
heat&boil	20 lb/kgal	0.0200	5 lb/kgal	0.005	1 lb/kgal	0.001	3 lb/kgal	0.003	3
Kulluk-SCR	1.0	0.0317	-	-	-	-	-	-	4
SCR	1.5	0.0476	-	-	-	-	-	-	5
Kulluk-OxyCat	-	-	-	-	-	-	0.20	0.0063	6
OxyCat-Lg	-	-	0.17	0.0230	0.027	0.0036	0.25	0.007926	7
OxyCat-Sm	-	-	0.19	0.0257	0.105	0.0142	0.60	0.019023	8
Nanuq	9	0.2853	-	-	-	-	-	-	9
CDPF-Lg	-	-	0.085	0.0115	0.009	0.001215	0.075	0.002378	10
Electric	0	0	0	0	0	0	0	0	NA

*PM2.5

References

None-Lg	1	NOx & PM: Recent stack test data, CO & VOC:AP-42 Table 3.4-1 Internal Combustion, Large Stationary Engines (fuel Input)-uncontrolled; ver. 10/1996
None-Sm	2	NOx & PM: Recent stack test data, CO & VOC: AP-42.Table 3.3-1 Internal Combustion, Diesel (fuel input)-uncontrolled; ver. 10/1996
heat&boil	3	NOx & PM: Recent Stack test data, CO & VOC: AP-42. Table 1.11-2 External Combustion, Small Boilers-waste oil; ver 10/1996
Kulluk-SCR	4	Emission factors based on stack tests from the Frontier Discoverer
SCR	5	Selective Catalytic Reduction NOx emission factor based on stack tests
Kulluk-OxyCat	6	PM: Tier 2 engines
OxyCat-Lg	7	Oxidation Catalyst controls applied to reference (1) emission factors
OxyCat-Sm	8	Oxidation Catalyst controls applied to reference (2) emission factors
Nanuq	9	CAT3806 Diesel Engine Technical data sheet
CDPF-Lg	10	Catalytic Diesel Particulate Filters controls applied to reference (1) emission factors

FUEL USE - MAX DAILY

Emission Units to permit:	Capacity Values		Capacity fuel - hourly MMBtu/hr	gal/hr		Max fuel - daily: MLC Case MMBtu	MLC Case gal	Drilling Case MMBtu	Drilling Case gal	Cementing/Logging Case MMBtu	Cementing/Logging Case gal
Kulluk emission units											
Generation	8,500	hp	50.58	375		1,214	8,991	1,214	8,991	857	6,347
MLC HPU'S	1,500	hp	10.50	78		252	1,867	0	0	0	0
Air compressors	1,500	hp	10.50	78		252	1,867	0	0	0	0
Cranes	900	hp	2.52	19		18	134	18	134	30	224
Heaters & Boilers	6	MMBtu/hr	6.00	44		144	1,067	144	1,067	144	1,067
Seldom-used units	150	gal/wk	0.12	0.89	group limit	3	21	3	21	3	21
			KULLUK - SUBTOTAL				*13,947*		*10,214*		*7,659*
Ice Management											
Propulsion & Generation	32,200	hp	225	1,670		5,410	40,071	5,410	40,071	5,410	40,071
Heaters & Boilers	10	MMBtu/hr	10	74		240	1,778	240	1,778	240	1,778
Seldom-used units	100	gal/wk	0.080	0.60	group limit	2	14	2	14	2	14
			ICE MANAGEMENT - SUBTOTAL				*41,863*		*41,863*		*41,863*
Anchor Handler											
Propulsion & Generation	32,200	hp	225	1,670		5,410	40,071	5,410	40,071	5,410	40,071
Heaters & Boilers	10	MMBtu/hr	10	74		240	1,778	240	1,778	240	1,778
Seldom-used units	100	gal/wk	0.080	0.60	group limit	2	14	2	14	2	14
			ANCHOR HANDLER - SUBTOTAL				*41,863*		*41,863*		*41,863*
Resupply Ship - transport mode											
Propulsion & Generation	12,000	hp	84	622		2,016	1,200	2,016	1,200	2,016	1,200
Seldom-used units	20	gal/wk	0.016	0.12	group limit	0.4	2.9	0.4	2.9	0.4	2.9
Resupply Ship - DP mode											
Propulsion & Generation	12,000	hp	84	622		2,016	4,800	2,016	4,800	2,016	4,800
Seldom-used units	20	gal/wk	0.016	0.12	group limit	0.4	2.9	0.4	2.9	0.4	2.9
			RESUPPLY SHIPS - SUBTOTAL				*6,006*		*6,006*		*6,006*
OSR vessel											
Propulsion & Generation	3,487	hp	16	117		378	2,800	378	2,800	378	2,800
Seldom-used units	100	gal/wk	0.080	0.60	group limit	2	14	2	14	2	14
Quartering vessel											
Propulsion & Generation	10,061	hp	39	292		945	7,000	945	7,000	945	7,000
Seldom-used units	100	gal/wk	0.080	0.60	group limit	2	14	2	14	2	14
OSR work boats											
Kvichaks	3,789	gal/wk	3.05	23		73	541	73	541	73	541
			OSR SHIPS - SUBTOTAL				*10,370*		*10,370*		*10,370*
			Total daily use				**114,049**		**110,316**		**107,761**

TOTAL WASTE INCINERATED

Incinerators	Capacity Values		MLC Case lbs/day	Drilling Case lbs/day	Cementing/Logging case lbs/day	Total lbs/day
Kulluk	276	lb/hr	3,312	3,312	3,312	9,936
Ice Management	154	lb/hr	3,696	3,696	3,696	11,088
Anchor Handler	154	lb/hr	3,696	3,696	3,696	11,088
OSR vessel	125	lb/hr	3,000	3,000	3,000	9,000
Quartering vessel	125	lb/hr	3,000	3,000	3,000	9,000
		total lbs/day	**16,704**	**16,704**	**16,704**	**50,112**

Kulluk Seldom Used-Split

Source			Capacity fuel - hourly MMBtu/hr	gal/hr		Max fuel - daily: MLC Case MMBtu	MLC Case gal	Drilling Case MMBtu	Drilling Case gal	Cementing/Logging Case MMBtu	Cementing/Logging Case gal
Seldom-used units w/o egen	566	gal/month	0.106	0.79	group limit	3	19	3	19	3	19
Kulluk Emergency Generator	77	gal/month	5.194	38.48	group limit	10	77	10	77	10	77

AIR SCIENCES INC. DENVER • PORTLAND	Air Sciences Inc. ENGINEERING CALCULATIONS	PROJECT TITLE: Shell - Exploration Drilling		BY: S. Pryor	
		PROJECT NO: 180-20-6	PAGE: 4	OF: 10	SHEET: 1
		SUBJECT: Kulluk / Beaufort Pmt App	DATE: January 7, 2011		

FUEL USE - MAX ANNUAL

Emission Units to permit:	Capacity Values	Capacity fuel - hourly		Max fuel - Annual (Modeling only)					
				MLC Case		Drilling Case		Cementing/Logging Case	
		MMBtu/hr	gal/hr	MMBtu	gal	MMBtu	gal	MMBtu	gal
Kulluk emission units									
Generation	8,500 hp	50.58	375	24,276	179,822	58,262	431,573	44,554	330,027
MLC HPU'S	1,500 hp	10.50	78	5,040	37,333	0	0	0	0
Air compressors	1,500 hp	10.50	78	5,040	37,333	0	0	0	0
Cranes	900 hp	2.52	19	363	2,688	871	6,451	1,572	11,648
Heaters & Boilers	6 MMBtu/hr	6.00	44	2,880	21,333	6,912	51,200	7,488	55,467
Seldom-used units	150 gal/wk	0.12	0.89 group limit	58	429	139	1,029	150	1,114
		KULLUK - SUBTOTAL			*278,939*		*490,253*		*398,256*
Ice Management									
Propulsion & Generation	32,200 hp	225	1670	41,113	304,540	98,671	730,897	106,894	791,805
Heaters & Boilers	10 MMBtu/hr	10	74	1,824	13,511	4,378	32,427	4,742	35,129
Seldom-used units	100 gal/wk	0.080	0.60 group limit	15	109	35	261	38	282
		ICE MANAGEMENT - SUBTOTAL			*318,160*		*763,584*		*827,216*
Anchor Handler									
Propulsion & Generation	32,200 hp	225	1670	41,113	304,540	98,671	730,897	106,894	791,805
Heaters & Boilers	10 MMBtu/hr	10	74	1,824	13,511	4,378	32,427	4,742	35,129
Seldom-used units	100 gal/wk	0.080	0.595 group limit	15	109	35	261	38	282
		ANCHOR HANDLER - SUBTOTAL			*318,160*		*763,584*		*827,216*
Resupply Ship - transport mode									
Propulsion & Generation	12,000 hp	84	622	40,320	9,600	96,768	23,040	104,832	24,960
Seldom-used units	20 gal/wk	0.016	0.12 group limit	8	57	19	137	20	149
Resupply Ship - DP mode									
Propulsion & Generation	12,000 hp	84	622	40,320	19,200	96,768	46,080	104,832	49,920
Seldom-used units	20 gal/wk	0.016	0.12 group limit	8	57	19	137	20	149
		RESUPPLY SHIPS - SUBTOTAL			*28,914*		*69,394*		*75,177*
OSR vessel									
Propulsion & Generation	3,487 hp	16	117	7,560	33,600	18,144	80,640	19,656	87,360
Seldom-used units	100 gal/wk	0.080	0.6 group limit	39	286	93	686	100	743
Quartering vessel									
Propulsion & Generation	10,061 hp	39	292	18,900	84,000	45,360	201,600	49,140	218,400
Seldom-used units	100 gal/wk	0.080	0.6 group limit	39	286	93	686	100	743
OSR work boats									
Kvichaks	3,789 gal/wk	3.05	23	1,462	10,827	3,508	25,984	3,800	28,149
		OSR SHIPS - SUBTOTAL			*128,998*		*309,595*		*335,395*
			Total Annual Use		**1,073,171**		**2,396,411**		**2,463,260**
				TOTAL ANNUAL GALLONS		**5,932,843**			

TOTAL WASTE INCINERATED

	Capacity Values	MLC Case	Drilling Case	Cementing/Logging case	Total
Incinerators		lbs/year	lbs/year	lbs/year	tons /year
Kulluk	276 lb/hr	66,240	158,976	172,224	199
Ice Management	154 lb/hr	28,090	67,415	73,033	84
Anchor Handler	154 lb/hr	28,090	67,415	73,033	84
OSR vessel	125 lb/hr	60,000	144,000	156,000	180
Quartering vessel	125 lb/hr	60,000	144,000	156,000	180
total lbs/yr		**242,419**	**581,806**	**630,290**	**727**

Kulluk Seldom Used-Split		Capacity fuel - hourly		Max fuel - Annual (Modeling only)					
				MLC Case		Drilling Case		Cementing/Logging Case	
Source		MMBtu/hr	gal/hr	MMBtu	gal	MMBtu	gal	MMBtu	gal
Seldom-used units w/o egen	566 gal/month	0.106	0.79 group limit	51	377	122	905	132	981
Kulluk Emergency Generator	77 gal/month	5.194	38.48 group limit	7	51	17	123	18	133

*This activity cannot occur simultaneously with Resupply - DP mode. DP mode has greater impacts.

NOx EMISSIONS - FOR IMPACT MODELING

shading represents owner requested limit to be demonstrated by documentation of daily fuel consumption

shading represents owner requested limit to be demonstrated by documentation of weekly fuel consumption

MLC_NOx_ppd Drill_NOx_ppd C/L_NOx_ppd NOx_tpy

Source	Emission Factor	unit	*lb/hr^*	lb/hr	Max *lb/day^*	MLC lb/day	DRILL lb/day	C/L lb/day	TOTAL ton/year
Kulluk emission units									
Generation	0.032	lb/gal		11.88	285	285	285	201	15
MLC HPU'S	0.476	lb/gal		36.99	888	888	0	0	9
Air compressors	0.380	lb/gal		29.59	710	710	0	0	7
Cranes	0.476	lb/gal		8.88	107	64	64	107	5
Heaters & Boilers	0.020	lb/gal		0.89	21	21	21	21	1
Seldom-used units	0.476	lb/gal		0.42	10.19	10.19	10.19	10.19	0.61
Ice Management									
Propulsion & Generation	0.048	lb/gal		79	1,906	1,906	1,906	1,906	43
Heaters & Boilers	0.020	lb/gal		1.48	36	36	36	36	0.81
Seldom-used units	0.476	lb/gal		0.28	6.79	6.79	6.79	6.79	0.15
Anchor Handler									
Propulsion & Generation	0.048	lb/gal		79	1,906	1,906	1,906	1,906	43
Heaters & Boilers	0.020	lb/gal		1.48	36	36	36	36	0.81
Seldom-used units	0.476	lb/gal		0.28	6.79	6.79	6.79	6.79	0.15
Resupply Ship - transport mode									
Propulsion & Generation	0.380	lb/gal	*237*	(0*)	457	(0*)	(0*)	(0*)	11
Seldom-used units	0.476	lb/gal	*0.057*	(0*)	1.36	(0*)	(0*)	(0*)	0.08
Resupply Ship - DP mode									
Propulsion & Generation	0.380	lb/gal		237	1,826	1,826	1,826	1,826	22
Seldom-used units	0.476	lb/gal		0.06	1.36	1.36	1.36	1.36	0.08
OSR vessel									
Propulsion & Generation	0.380	lb/gal		44	1,065	1,065	1,065	1,065	38
Seldom-used units	0.476	lb/gal		0.28	6.79	6.79	6.79	6.79	0.41
Quartering vessel									
Propulsion & Generation	0.285	lb/gal		83	1,997	1,997	1,997	1,997	72
Seldom-used units	0.476	lb/gal		0.28	6.79	6.79	6.79	6.79	0.41
OSR work boats									
Kvichaks	0.476	lb/gal		11	257	257	257	257	15
TOTAL				**627**	**11,537**	**11,036**	**9,438**	**9,397**	**286**

I_NOx_ppd I_NOx_tpy

NO_X EMISSIONS

Source	Emission Factor NO_X	unit	NO_X lb/hr	NO_X lb/day	NO_X ton/year
Incinerators					
Kulluk	3	lb/ton	0.41	4.97	0.30
Ice Management	3	lb/ton	0.23	5.54	0.13
Anchor Handler	3	lb/ton	0.23	5.54	0.13
OSR vessel	3	lb/ton	0.19	4.50	0.27
Quartering vessel	3	lb/ton	0.19	4.50	0.27
			1.25	**25.06**	**1.09**

EF references	pollutant	EF	unit	reference
Incinerators	NO_X	3	lb/ton	AP42 Table 2.1-12, 10/96

Kulluk Seldom Used-Split

Source	Emission Factor	unit	*lb/hr^*	lb/hr	Max *lb/day^*	MLC lb/day	DRILL lb/day	C/L lb/day	TOTAL ton/year
Seldom-used units w/o egen	0.476	lb/gal		0.37	8.97	8.97	8.97	8.97	0.54
Kulluk Emergency Generator	0.476	lb/gal		18.30	36.60	36.60	36.60	36.60	0.07

*This activity cannot occur simultaneously with Resupply - DP mode. DP mode has greater impacts.

^Values in this column represent maximum emissions independent of activity.

$PM_{2.5}$ EMISSIONS - FOR IMPACT MODELING

shading represents owner requested limit to be demonstrated by documentation of daily fuel consumption

shading represents owner requested limit to be demonstrated by documentation of weekly fuel consumption

MLC_PM_ppd Drill_PM_ppd C/L_PM_ppd PM_tpy

Source	Emission Factor	unit	*lb/hr^*	lb/hr	Max *lb/day^*	MLC lb/day	DRILL lb/day	C/L lb/day	TOTAL ton/year
Kulluk emission units									
Generation	0.008	lb/gal		2.97	71	71	71	50	3.73
MLC HPU'S	0.019	lb/gal		1.48	36	36	0	0	0.36
Air compressors	0.008	lb/gal		0.62	15	15	0	0	0.15
Cranes	0.019	lb/gal		0.36	4	3	3	4	0.20
Heaters & Boilers	0.003	lb/gal		0.15	4	4	4	4	0.21
Seldom-used units	0.038	lb/gal		0.03	0.82	0.82	0.82	0.82	0.05
Ice Management									
Propulsion & Generation	0.008	lb/gal		13	318	318	318	318	7
Heaters & Boilers	0.003	lb/gal		0.24	6	6	6	6	0.13
Seldom-used units	0.038	lb/gal		0.02	0.54	0.54	0.54	0.54	0.01
Anchor Handler									
Propulsion & Generation	0.008	lb/gal		13	318	318	318	318	7
Heaters & Boilers	0.003	lb/gal		0.24	6	6	6	6	0.13
Seldom-used units	0.038	lb/gal		0.02	0.54	0.54	0.54	0.54	0.01
Resupply Ship - transport mode									
Propulsion & Generation	0.016	lb/gal	*10*	(0*)	19	0	0	0	0
Seldom-used units	0.038	lb/gal	*0.0045*	(0*)	0.11	0.00	0.00	0.00	0.01
Resupply Ship - DP mode									
Propulsion & Generation	0.016	lb/gal		10	76	76	76	76	1
Seldom-used units	0.038	lb/gal		0.00	0.11	0.11	0.11	0.11	0.01
OSR vessel									
Propulsion & Generation	0.016	lb/gal		2	44	44	44	44	2
Seldom-used units	0.038	lb/gal		0.02	0.54	0.54	0.54	0.54	0.03
Quartering vessel									
Propulsion & Generation	0.002	lb/gal		1	17	17	17	17	1
Seldom-used units	0.038	lb/gal		0.02	0.54	0.54	0.54	0.54	0.03
OSR work boats									
Kvichaks	0.038	lb/gal		0.86	21	21	21	21	1
TOTAL				**46**	**956**	**935**	**885**	**866**	**24**

I_PM10_ppd I_PM25_ppd I_PM10_tpy I_PM25_tpy

PM_{10} & $PM_{2.5}$ EMISSIONS

Source	Emission Factor PM_{10}	Emission Factor $PM_{2.5}$	unit	PM_{10} lb/hr	$PM_{2.5}$ lb/hr	PM_{10} lb/day	$PM_{2.5}$ lb/day	PM_{10} ton/year	$PM_{2.5}$ ton/year
Incinerators									
Kulluk	16.4	14	lb/ton	2.26	1.93	27.16	23.18	1.63	1.39
Ice Management	16.4	14	lb/ton	1.26	1.08	30.31	25.87	0.69	0.59
Anchor Handler	16.4	14	lb/ton	1.26	1.08	30.31	25.87	0.69	0.59
OSR vessel	16.4	14	lb/ton	1.03	0.88	24.60	21.00	1.48	1.26
Quartering vessel	16.4	14	lb/ton	1.03	0.88	24.60	21.00	1.48	1.26
				6.84	**5.84**	**136.97**	**116.93**	**5.96**	**5.09**

EF references	pollutant	EF	unit	reference
Incinerators	PM_{10}	16.4	lb/ton	Disco Stack Test June 2010 (multiplied by a safety factor of 2)
	$PM_{2.5}$	14	lb/ton	Disco Stack Test June 2010 (multiplied by a safety factor of 2)

Kulluk Seldom Used-Split

Source	Emission Factor	unit	*lb/hr^*	lb/hr	Max *lb/day^*	MLC lb/day	DRILL lb/day	C/L lb/day	TOTAL ton/year
Seldom-used units w/o egen	0.038	lb/gal		0.03	0.72	0.72	0.72	0.72	0.04
Kulluk Emergency Generator	0.038	lb/gal		1.46	2.93	2.93	2.93	2.93	0.01

*This activity cannot occur simultaneously with Resupply - DP mode. DP mode has greater impacts.

^Values in this column represent maximum emissions independent of activity.

Air Sciences Inc.	PROJECT TITLE: Shell - Exploration Drilling		BY: S. Pryor	
AIR SCIENCES INC. DENVER • PORTLAND	PROJECT NO: 180-20-6	PAGE: 7	OF: 10	SHEET: 1
ENGINEERING CALCULATIONS	SUBJECT: Kulluk / Beaufort Pmt App		DATE: January 7, 2011	

CO EMISSIONS - FOR IMPACT MODELING

						MLC_CO_ppd	Drill_CO_ppd	C/L_CO_ppd	CO_tpy
					Max	MLC	DRILL	C/L	TOTAL
Source	Emission Factor	unit	*lb/hr^*	lb/hr	*lb/day^*	lb/day	lb/day	lb/day	ton/year
Kulluk emission units									
Generation	0.023	lb/gal		8.60	206	206	206	146	10.80
MLC HPU'S	0.026	lb/gal		2.00	48	48	0	0	0.48
Air compressors	0.023	lb/gal		1.79	43	43	0	0	0.43
Cranes	0.026	lb/gal		0.48	6	3	3	6	0.27
Heaters & Boilers	0.005	lb/gal		0.22	5	5	5	5	0.32
Seldom-used units	0.128	lb/gal		0.11	2.75	2.75	2.75	2.75	0.16
Ice Management									
Propulsion & Generation	0.023	lb/gal		38.32	920	920	920	920	21
Heaters & Boilers	0.005	lb/gal		0.37	9	9	9	9	0.20
Seldom-used units	0.128	lb/gal		0.08	1.83	1.83	1.83	1.83	0.04
Anchor Handler									
Propulsion & Generation	0.023	lb/gal		38.32	920	920	920	920	21
Heaters & Boilers	0.005	lb/gal		0.37	9	9	9	9	0.20
Seldom-used units	0.128	lb/gal		0.08	1.83	1.83	1.83	1.83	0.04
Resupply Ship - transport mode									
Propulsion & Generation	0.115	lb/gal	*71*	(0*)	138	(0*)	(0*)	(0*)	3
Seldom-used units	0.128	lb/gal	*0.015*	(0*)	0.37	(0*)	(0*)	(0*)	0.02
Resupply Ship - DP mode									
Propulsion & Generation	0.115	lb/gal		71.40	551	551	551	551	7
Seldom-used units	0.128	lb/gal		0.02	0.37	0.37	0.37	0.37	0.02
OSR vessel									
Propulsion & Generation	0.115	lb/gal		13	321	321	321	321	12
Seldom-used units	0.128	lb/gal		0.08	1.83	1.83	1.83	1.83	0.11
Quartering vessel									
Propulsion & Generation	0.011	lb/gal		3	80	80	80	80	3
Seldom-used units	0.128	lb/gal		0.08	1.83	1.83	1.83	1.83	0.11
OSR work boats									
Kvichaks	0.128	lb/gal		3	69	69	69	69	4
TOTAL				**182**	**3,336**	**3,195**	**3,104**	**3,046**	**84**

CO EMISSIONS

				I_CO_ppd	I_CO_tpy
	Emission Factor		CO	CO	CO
Source	CO	unit	lb/hr	lb/day	ton/year
Incinerators					
Kulluk	300	lb/ton	41.40	496.80	29.81
Ice Management	300	lb/ton	23.10	554.40	12.64
Anchor Handler	300	lb/ton	23.10	554.40	12.64
OSR vessel	300	lb/ton	18.75	450.00	27.00
Quartering vessel	300	lb/ton	18.75	450.00	27.00
			125.10	**2,505.60**	**109.09**

EF references	pollutant	EF	unit	reference
Incinerators	CO	300	lb/ton	AP42 Table 2.1-12, 10/96

Kulluk Seldom Used-Split

					Max	MLC	DRILL	C/L	TOTAL
Source	Emission Factor	unit	*lb/hr^*	lb/hr	*lb/day^*	lb/day	lb/day	lb/day	ton/year
Seldom-used units w/o egen	0.128	lb/gal		0.10	2.42	2.42	2.42	2.42	0.15
Kulluk Emergency Generator	0.128	lb/gal		4.93	9.87	9.87	9.87	9.87	0.02

*This activity cannot occur simultaneously with Resupply - DP mode. DP mode has greater impacts.

^Values in this column represent maximum emissions independent of activity.

SO_2 EMISSIONS - FOR IMPACT MODELING

MLC_SO2_ppd Drill_SO2_ppd C/L_SO2_ppd SO2_tpy

Source	Emission Factor	unit	*lb/hr^*	lb/hr	Max *lb/day^*	MLC lb/day	DRILL lb/day	C/L lb/day	TOTAL ton/year
Kulluk emission units									
Generation	0.001419	lb/gal		0.53	12.75	12.75	12.75	9.00	0.67
MLC HPU'S	0.001419	lb/gal		0.11	2.65	2.65	0	0	0.03
Air compressors	0.001419	lb/gal		0.11	2.65	2.65	0	0	0.03
Cranes	0.001419	lb/gal		0.03	0.32	0.19	0.19	0.32	0.01
Heaters & Boilers	0.001419	lb/gal		0.06	1.51	1.51	1.51	1.51	0.09
Seldom-used units	0.001419	lb/gal		0.0013	0.0304	0.0304	0.0304	0.0304	0.0018
Ice Management									
Propulsion & Generation	0.001419	lb/gal		2.37	56.84	56.84	56.84	56.84	1.30
Heaters & Boilers	0.001419	lb/gal		0.11	2.52	2.52	2.52	2.52	0.06
Seldom-used units	0.001419	lb/gal		0.0008	0.0203	0.0203	0.0203	0.0203	0.0005
Anchor Handler									
Propulsion & Generation	0.001419	lb/gal		2.37	56.84	56.84	56.84	56.84	1.30
Heaters & Boilers	0.001419	lb/gal		0.11	2.52	2.52	2.52	2.52	0.06
Seldom-used units	0.001419	lb/gal		0.0008	0.0203	0.0203	0.0203	0.0203	0.0005
Resupply Ship - transport mode									
Propulsion & Generation	0.001419	lb/gal	*0.88*	(0*)	1.70	(0*)	(0*)	(0*)	0.04
Seldom-used units	0.001419	lb/gal	*0.000169*	(0*)	0.0041	(0*)	(0*)	(0*)	0.000243
Resupply Ship - DP mode									
Propulsion & Generation	0.001419	lb/gal		0.88	6.81	6.81	6.81	6.81	0.08
Seldom-used units	0.001419	lb/gal		0.0002	0.0041	0.0041	0.0041	0.0041	0.0002
OSR vessel									
Propulsion & Generation	0.001419	lb/gal		0.17	3.97	3.97	3.97	3.97	0.14
Seldom-used units	0.001419	lb/gal		0.0008	0.0203	0.0203	0.0203	0.0203	0.0012
Quartering vessel									
Propulsion & Generation	0.001419	lb/gal		0.41	9.93	9.93	9.93	9.93	0.36
Seldom-used units	0.001419	lb/gal		0.0008	0.0203	0.0203	0.0203	0.0203	0.0012
OSR work boats									
Kvichaks	0.001419	lb/gal		0.03	0.77	0.77	0.77	0.77	0.05
TOTAL				**7**	**162**	**160**	**155**	**151**	**4**

I_SO2_ppd I_SO2_tpy

SO_2 EMISSIONS

Source	Emission Factor SO_2	unit	SO_2 lb/hr	SO_2 lb/day	SO_2 ton/year
Incinerators					
Kulluk	2.5	lb/ton	0.35	4.14	0.25
Ice Management	2.5	lb/ton	0.19	4.62	0.11
Anchor Handler	2.5	lb/ton	0.19	4.62	0.11
OSR vessel	2.5	lb/ton	0.16	3.75	0.23
Quartering vessel	2.5	lb/ton	0.16	3.75	0.23
			1.04	**20.88**	**0.91**

EF references	pollutant	EF	unit	reference
Incinerators	SO_2	2.5	lb/ton	AP42 Table 2.1-12, 10/96

S = the weight % Sulfur in the Fuel 0.0100% 0.0105 lb/MMBtu

Kulluk Seldom Used-Split

Source	Emission Factor	unit	*lb/hr^*	lb/hr	Max *lb/day^*	MLC lb/day	DRILL lb/day	C/L lb/day	TOTAL ton/year
Seldom-used units w/o egen	0.001419	lb/gal		0.0011	0.0268	0.0268	0.0268	0.0268	0.0016
Kulluk Emergency Generator	0.001419	lb/gal		0.0546	0.1092	0.1092	0.1092	0.1092	0.0002

*This activity cannot occur simultaneously with Resupply - DP mode. DP mode has greater impacts.

^Values in this column represent maximum emissions independent of activity.

VOC EMISSIONS - FOR IMPACT MODELING

MLC_VOC_ppd Drill_VOC_ppd C/L_VOC_ppd VOC_tpy

Source	Emission Factor	unit	*lb/hr^*	lb/hr	Max *lb/day^*	MLC lb/day	DRILL lb/day	C/L lb/day	TOTAL ton/year
Kulluk emission units									
Generation	0.004	lb/gal		1.37	32.77	32.77	32.77	23.13	1.72
MLC HPU'S	0.014	lb/gal		1.10	26.46	26.46	0	0	0.26
Air compressors	0.004	lb/gal		0.28	6.80	6.80	0	0	0.07
Cranes	0.014	lb/gal		0.26	3.18	1.91	1.91	3.18	0.15
Heaters & Boilers	0.001	lb/gal		0.04	1.07	1.07	1.07	1.07	0.06
Seldom-used units	0.047	lb/gal		0.04	1.01	1.01	1.01	1.01	0.06
Ice Management									
Propulsion & Generation	0.004	lb/gal		6.09	146.06	146.06	146.06	146.06	3.33
Heaters & Boilers	0.001	lb/gal		0.07	1.78	1.78	1.78	1.78	0.04
Seldom-used units	0.047	lb/gal		0.03	0.68	0.68	0.68	0.68	0.02
Anchor Handler									
Propulsion & Generation	0.004	lb/gal		6.09	146.06	146.06	146.06	146.06	3.33
Heaters & Boilers	0.001	lb/gal		0.07	1.78	1.78	1.78	1.78	0.04
Seldom-used units	0.047	lb/gal		0.03	0.68	0.68	0.68	0.68	0.02
Resupply Ship - transport mode									
Propulsion & Generation	0.012	lb/gal	*7.6*	(0*)	15	(0*)	(0*)	(0*)	0.3
Seldom-used units	0.047	lb/gal	*0.0*	(0*)	0.1	(0*)	(0*)	(0*)	0.008
Resupply Ship - DP mode									
Propulsion & Generation	0.012	lb/gal		7.56	58.32	58.32	58.32	58.32	0.70
Seldom-used units	0.047	lb/gal		0.01	0.14	0.14	0.14	0.14	0.01
OSR vessel									
Propulsion & Generation	0.012	lb/gal		1.42	34.02	34.02	34.02	34.02	1.22
Seldom-used units	0.047	lb/gal		0.03	0.68	0.68	0.68	0.68	0.04
Quartering vessel									
Propulsion & Generation	0.001	lb/gal		0.35	8.51	8.51	8.51	8.51	0.31
Seldom-used units	0.047	lb/gal		0.03	0.68	0.68	0.68	0.68	0.04
OSR work boats									
Kvichaks	0.047	lb/gal		1.07	25.58	25.58	25.58	25.58	1.53
TOTAL				**26**	**511**	**495**	**462**	**453**	**13**

I_VOC_ppd I_VOC_tpy

VOC EMISSIONS

Source	Emission Factor VOC	unit	VOC lb/hr	VOC lb/day	VOC ton/year
Incinerators					
Kulluk	100	lb/ton	13.80	165.60	9.94
Ice Management	100	lb/ton	7.70	184.80	4.21
Anchor Handler	100	lb/ton	7.70	184.80	4.21
OSR vessel	100	lb/ton	6.25	150.00	9.00
Quartering vessel	100	lb/ton	6.25	150.00	9.00
			41.70	**835.20**	**36.36**

EF references	pollutant	EF	unit	reference
Incinerators	VOC	100	lb/ton	AP42 Table 2.1-12, 10/96

Kulluk Seldom Used-Split

Source	Emission Factor	unit	*lb/hr^*	lb/hr	Max *lb/day^*	MLC lb/day	DRILL lb/day	C/L lb/day	TOTAL ton/year
Seldom-used units w/o egen	0.047	lb/gal		0.04	0.89	0.89	0.89	0.89	0.05
Kulluk Emergency Generator	0.047	lb/gal		1.82	3.64	3.64	3.64	3.64	0.01

*This activity cannot occur simultaneously with Resupply - DP mode. DP mode has greater impacts.
^Values in this column represent maximum emissions independent of activity.

Total Annual Fuel 5,932,843 gallons
800,934 MMBtu

Sulfur emission control by fuel quality

	% wt	EF	unit	SO_2 ton/year
Use of 15 ppm (ULSD)	0.0015%	0.0016	lb/MMBtu	0.631
Use of 100 ppm	0.0100%	0.0105	lb/MMBtu	4.208
Use of 500 ppm (LSD)	0.050%	0.0525	lb/MMBtu	21.040
Use of 2500 ppm (0.25%) sulfur (standard)	0.250%	0.2627	lb/MMBtu	105.198

Greenhouse Gas Emissions

Reference

CO_2e $(CO_2 + CH_4*21 + N_2O*310)$ 40 CFR 98, Table A-1

		multiplier	EF	unit	ton/year	Reference
CO_2	comb	1	78.8	kg/MMBtu	**69,571**	Appendix B* Table B-3 [Distillate Fuel Oil (#1, 2, & 4)] May 2008
CH_4	comb	21	11	g/MMBtu	**204**	Appendix A* (Petroleum-Commercial) May 2008
N_20	comb	310	0.6	g/MMBtu	**164**	Appendix A* (Petroleum-Commercial) May 2008
CH_4	offgas	21	399	lb	**4**	Methane Mass Caculation.xls October 22,2010
annual CO_2e (tons)					**69,943**	

* EPA Climate Leaders, Greenhouse Gas Inventory Protocol Core Module Guidance; "Direct Emissions from Stationary Combustion Sources"
http://www.epa.gov/climateleaders/documents/resources/stationarycombustionguidance.pdf

APPENDIX B

Preparation of AERMOD Meteorological Data Input Files

ENVIRON

January 7, 2011

MEMORANDUM

To: Tim Martin – Air Sciences

From: Ken Richmond - ENVIRON

Subject: Meteorological Data Preparation for the Beaufort and Chukchi Seas

---

1 AERMOD Meteorological Data Input Files

The meteorological data sets for the AERMOD simulations in the Beaufort and Chukchi Seas will be prepared using a combination of the EPA *Guideline* AERMET meteorological preprocessor and an alternative method for periods of open-water. The proposed alternative approach bypasses the AERMET meteorological preprocessor using the Coupled Ocean Atmosphere Response Experiment (COARE) air-sea flux algorithm[1] and overwater meteorological measurements. ENVIRON compared this proposed COARE-AERMOD approach to the current guideline OCD model[2] for conditions in the Arctic and also conducted a model performance evaluation using data from offshore tracer experiments to demonstrate alternative COARE-AERMOD approach was not biased towards underestimates.[3]

AERMET will be applied to data collected when the surface is characterized by sea-ice using characteristic geophysical parameters for such conditions in the Arctic. This is the same general EPA *Guideline* method for permitting onshore sources. Such conditions are prevalent at the beginning and end of the June through November offshore drilling season. For periods of open-water in the summer and fall, AERMET will be replaced by the COARE air-sea flux algorithms applied to marine meteorological measurements supplemented by techniques to estimate characteristic mixing heights. The period of "open-water" will be defined based on the availability of buoy data. In 2009 and 2010, Shell deployed buoys in the Chukchi and Beaufort Seas when the pack-ice allowed in late July or August. The buoys were in place until they were either destroyed or their operation affected by the pack-ice in October. The remainder of this section will describe the proposed methods for preparing the meteorological input files needed

---

[1] Version 3.0 of the COARE algorithm with journal references and a User's Manual can be accessed at: ftp://ftp.etl.noaa.gov/users/cfairall/wcrp_wgsf/computer_programs/cor3_0/ and http://www.coaps.fsu.edu/COARE/flux_algor/

[2] ENVIRON 2010a. *Comparison of OCD vs. COARE-AERMOD, Support for Simulation of Shell Exploratory Drilling Sources in the Beaufort and Chukchi Seas.* ENVIRON, 19020 33rd Ave W, Suite 310, Lynnwood, WA 98036; Job No. 0322090, October 24, 2010.

[3] ENVIRON 2010b. *Evaluation of the COARE-AERMOD Alternative Modeling Approach, Support for Simulation of Shell Exploratory Drilling Sources In the Beaufort and Chukchi Seas.* ENVIRON, 19020 33rd Ave W, Suite 310, Lynnwood, WA 98036; Job No. 0322090, December 16, 2010.

by AERMOD for these two basic conditions: Sea-ice and Open-water. The discussion will focus on the Beaufort Sea data sets followed by planned modifications for the Chukchi Sea. A summary table of these issues has also been prepared and is attached.

1.1 Beaufort AERMET Sea-Ice Period

The modeling approach will assume the techniques embodied in the AERMET are applicable to periods of the drilling season when the meteorology is not dominated by the effects of open-water. Open-water in this protocol is defined as the period when the sea-ice allows the deployment of a buoy. The periods of the available Beaufort Sea buoy data are from August 5 and October 13, 2009; and August 14 and October 10, 2010. Prior to and following the open-water periods during the June to November drilling season, AERMET will be applied using the same general techniques as are applied to permitting for onshore sources. The input parameters and data sources are:

- Onsite surface data: Surface data from the Reindeer Island 10 tower will be used to provide wind speed, wind direction, air temperature, differential temperature between 10 m and 2 m, solar radiation and pressure.
- NWS data: NWS data from Deadhorse will be collected and processed by AERMET. These data are primarily used for periods of missing onsite data and an alternative method for predicting the surface energy fluxes. Note, there are almost no missing Reindeer Island data for 2009 and 2010
- Optional horizontal and vertical turbulent intensities: Reindeer Island 10 m sigma-theta and sigma-w observations will be included in the AERMET input files and passed through to AERMOD for dispersion estimates.
- Upper air data: Twice daily soundings from the Barrow NWS site will be provided to AERMET for the prediction of the convective mixing heights and temperature gradients above the mixing height.
- Surface geophysical parameters: The albedo, Bowen ratio and the surface roughness length will be set to 0.8, 2.0, and 0.001 m for the entire period. These settings were recommended by ADEC in recent previous permit applications for the Beaufort Sea.

1.2 Beaufort Sea COARE-AERMOD Overwater Data Set

The COARE-AERMOD meteorological data preparation involves two steps: 1) application of the COARE bulk air-sea flux algorithms to estimate the surface energy fluxes and 2) assembly of the meteorological data from the COARE algorithm with additional variables needed by AERMOD. A FORTRAN program was written that calls the COARE bulk air-sea flux algorithm subroutines provided by the authors of the method.[1] Mixing height estimates and several other variables needed by AERMOD are not part of the COARE routines. Mixing heights will be provided separately using several techniques based on the data from Barrow and the Endeavor Island thermal profiler. Further details are provided in the following discussion.

1.2.1 Data for COARE Algorithm

The COARE algorithm will be applied to predict the surface energy fluxes from the overwater data sets briefly described above. The data necessary for the COARE algorithm depend on the options employed for estimating the surface roughness, for the treatment of a cool-skin, or heating of the upper layer of the ocean. The proposed options and associated data are as follows:

- Several options are available to adjust the sea temperature to account for the difference between the skin temperature and the bulk temperature measurement taken at depth from a buoy or ship. Model comparison tests have shown the COARE algorithm is not sensitive to these options for conditions in the Arctic Ocean.[2] The cool-skin and warm layer options will not be selected for the current study.
- COARE also contains several methods for estimating the surface roughness length, and the routines can use wave height and period measurement data. The proposed simulations will be conducted with the default option for a well-developed or deep sea. As with the warm-layer and cool-skin options, ENVIRON sensitivity tests suggest the COARE algorithm is not very sensitive to the surface roughness options, especially in the absence of wave measurement data.
- The air-sea temperature difference, overwater relative humidity and the wind velocity drive the energy fluxes and surface stability routines within the COARE routines. The air-sea temperature difference and humidity data will be taken from the buoy measurements. Shell deployed two buoys in the Beaufort Sea during both 2009 and 2010. The Reindeer Island buoy will be used when these data are available supplemented by a buoy deployed by Shell near the Sivulliq prospect. The Sivulliq buoys extend the open-water periods in the 2009 and 2010 data sets. For each year, these buoys were left in the Beaufort Sea until they were destroyed by the pack-ice.
- The Reindeer Island 10 m observations will be used for wind speed. Reindeer Island is a small offshore island with very little terrain relief, and the tower is located very close to the edge of the narrow island. It is assumed the 10 m winds are embedded within the marine boundary layer and are not influenced by the island. This assumption can be supported by comparisons with nearby offshore winds and air temperatures.
- Surface pressure is used to calculate air density and will also be from the Reindeer Island observations.
- The COARE algorithm has a small term that depends on rainfall. Deadhorse Airport observations will be provided for the calculations.
- The COARE algorithm has a small term for "gustiness" that adds to the momentum fluxes during light winds caused by large scale eddies. For COARE a constant estimate of 200m will be assumed based on typical mixed layer heights in the Arctic during summer and fall.[4]

Surface energy flux estimates from the COARE algorithm will be combined with measurements and reformatted according to the techniques discussed in the next section.

1.2.2 AERMOD Meteorological Data Assembly

The open-water meteorological data for the AERMOD simulations will be prepared from the COARE algorithm estimates of the energy fluxes using the data described above and other measurements from the Arctic. The assembly of the necessary input data will be accomplished in

[4] Kahl, J.D. 1990. Characteristics of the Low-Level Temperature Inversion along the Alaskan Arctic Coast. *Int. J. of Climatology*, Vol. 10, 537-548.

a spreadsheet, where the input data will be reformatted to mimic the output from AERMET. The options selected for the simulations and associated data are as follows:

- Reindeer Island 10 m wind speed, wind direction, and air temperature data will be used.
- Reindeer Island 10 m sigma-theta and sigma-w observations will be passed through to AERMOD for dispersion estimates.
- Surface roughness lengths will be estimated by the COARE algorithm using the default option for a well-developed sea based on friction velocity.
- Monin-Obukhov length (*L*) and surface friction velocity ( ) will be from COARE algorithm estimates. Based on the results of ENVIRON's comparisons to OCD and the model performance study, the Monin-Obukhov length will be restricted such that ABS (*L*) > 5. This restriction avoids unrealistic extremely stable and unstable conditions during light wind conditions. For consistency, the surface friction velocity output from COARE will be adjusted to impose such restrictions.
- Mechanical mixing heights (z_{im}) will be calculated from the surface friction velocity using the Venketram equation employed by AERMET:

  The estimates will also be temporally smoothed using the same method as in AERMET. For low winds and smooth surfaces the Venketram equation above results in very small mechanical mixing heights. In order to avoid numerical problems and possible extrapolation of algorithms beyond their intended applications, the minimum mechanical mixing height will be at 25 m.
- Convective boundary layer heights will be set to mixing heights when conditions are unstable as indicated by the Monin-Obukhov length ($L < 0$). The boundary layer height will be diagnosed from the Reindeer Island profiler data during 2010 and from the Barrow twice daily soundings in 2009 using a bulk Richardson number technique.[5] Preliminary comparisons conducted during the Endeavor Island profiler audits suggest the base of temperature inversions at Barrow were similar to the observed profilers in the Beaufort Sea.
- Convective velocity scales will be calculated from the convective mixed layer height (z_{ic}), friction velocity ( ), and Monin-Obukhov length (*L*):
- The vertical potential temperature gradient above the convective boundary layer will be derived from the same data sets used for the convective mixed layer heights.
- Miscellaneous variables used by the AERMOD deposition algorithm (not used in the simulations):
  - Sensible heat fluxes will be set to the estimates from the COARE algorithm.

[5] Gryning, S.E. and Batchvarova, 2003. Marine Boundary-Layer Height Estimation from NWP Model Output. *Int. J. Environ. Pollut*. Vol 20, 147-153.

  - Relative humidity will be from the buoy observations
  - Bowen ratios will be calculated from the COARE predicted sensible and latent heat fluxes.
  - Albedo will be set to the COARE default of 0.055.
  - The cloud cover fraction will be from the Deadhorse NWS observations.
  - Precipitation amount and code will be set as missing.
  - Surface pressure will be from the Reindeer Island observations

1.3 Chukchi Sea AERMET Sea-Ice Period

The preparation of meteorological data for the Chukchi Sea will follow the same basis principles as for the Beaufort Sea except different data sets will be used. AERMET will be applied during the periods of the year where meteorological conditions are dominated by the effects of sea-ice, while open-water periods will be characterized using the COARE algorithm and buoy measurements. Prior to and following the open-water periods during the June to November drilling season, AERMET will be applied using the same general techniques as are applied to permitting for onshore sources. The input parameters and data sources are:

- Onsite surface data: Data are not collected near the location of the Burger prospect during periods of sea-ice and onsite conditions during these periods will be characterized using data collected by Shell at the Pt. Lay coastal site. For 2010, surface data from the Pt. Lay 10 m tower will be used to provide wind speed, wind direction, air temperature, differential temperature between 10 m and 2 m, solar radiation and pressure. In 2009, data for the "onsite" AERMET pathway are not available and surface data from the Wainwright NWS station will be used.
- NWS data: NWS data from Wainwright will be collected and processed by AERMET. These surface observations of wind speed, temperature, cloud cover and other variables will be used by AERMET to derive the surface energy fluxes in 2009. In 2010, these data will primarily be used for periods of missing "onsite" Pt. Lay data.
- Optional horizontal and vertical turbulent intensities: Pt. Lay 10 m sigma-theta and sigma-w observations will be included in the AERMET input files and passed through to AERMOD for dispersion estimates. These data are available for 2010.
- Upper air data: Twice daily soundings from the Barrow NWS site will be provided to AERMET for the prediction of the convective mixing heights and temperature gradient above the mixing height.
- Surface geophysical parameters: As in the Beaufort Sea, the albedo, Bowen ratio and the surface roughness length will be set to 0.8, 2.0, and 0.001 m for the entire period.

1.4 Chukchi Sea COARE-AERMOD Overwater Data Set

The offshore data available for the Chukchi Sea are less extensive than for the Beaufort Sea, especially during 2009 when only a month of data are available from a buoy deployed near the Burger prospect. In order to supplement these data during 2009, data from the Beaufort Sea buoys will be used to extend the period of open-water data. The Chukchi "open-water" periods will be August 5 to October 13, 2009; and July 27 to October 18, 2010. Further details concerning the application of the COARE bulk air-sea flux algorithms to estimate the surface energy fluxes and assembly of the meteorological data from the COARE algorithm with additional variables needed by AERMOD are provided in the following discussion.

1.4.1 Data for COARE Algorithm

The COARE algorithm will be applied to predict the surface energy fluxes from the overwater data sets using the same basic assumptions as used in the Beaufort Sea. The COARE algorithm will be applied using the default option for estimating the surface roughness, cool-skin option turned off, and warm-layer heating turned off. The proposed data sets are as follows:

- Buoy observations will be used for the air temperature, air-sea temperature difference, overwater relative humidity, and the wind velocity for COARE flux estimates. Data from buoys near the Burger prospect are available during August 24, 2009 to September 30, 2009; and July 27, 2010 to October 18, 2010.

  In 2009, the Burger buoy missed a significant fraction of the open-water season. In order to compliment these data, observations from the Beaufort Sea will be used to extend the open-water simulations from August 5 to October 13, 2009. Based on comparisons during periods where both data sets were available, conditions in the Chukchi Sea tended to be windier and the boundary layer more unstable than in the Beaufort Sea. Such tendencies will generally result in more dispersive conditions and the substitution of Beaufort overwater data will result in more conservative simulations.

- Surface pressure and precipitation will be from the Wainwright NWS observations.

- The COARE algorithm has a small term for "gustiness" that adds to the momentum fluxes during light winds caused by large scale eddies. For COARE a constant estimate of 200m will be assumed based on typical mixed layer heights in the Arctic during summer and fall.[4]

Surface energy flux estimates from the COARE algorithm will be combined with measurements and reformatted according to the techniques discussed in the next section.

1.4.2 AERMOD Meteorological Data Assembly

The open-water meteorological data for the AERMOD simulations will be prepared from the COARE algorithm estimates of the energy fluxes using the data described above and other measurements from the Arctic. The assembly of the necessary input data will be accomplished in a spreadsheet, where the input data will be reformatted to mimic the output from AERMET. The options selected for the simulations and associated data are as follows:

- Offshore wind speed, wind direction, and air temperature data from the Burger buoys will be used when available. In 2009, wind speed and air temperature data will be supplemented by data from the Beaufort Sea as explained above. During periods of overlapping data, wind directions in the Chukchi more closely resembles observations at Wainwright. Wainwright NWS wind directions will be used during open-water periods when data from the Burger buoy are not available in 2009.

- Optional offshore sigma-theta and sigma-w observations are not available for AERMOD and dispersion estimates will be based on AERMOD's internal algorithms that parameterize these variables based on the surface energy fluxes and mixed layer heights.

- Surface roughness lengths will be estimated by the COARE algorithm using the default option for a well-developed sea based on friction velocity.
- Monin-Obukhov length (*L*) and surface friction velocity ( ) will be from COARE algorithm estimates with the restriction that ABS (*L*) > 5.
- Mechanical mixing heights (z_{im}) will be calculated from the surface friction velocity using the Venketram equation employed by AERMET with a minimum mechanical mixing height of 25 m.
- Convective boundary layer heights will be set to mixing heights when conditions are unstable as indicated by the Monin-Obukhov length ($L < 0$). These estimates will be based on interpretation of the Barrow twice-daily soundings or from an algorithm based on comparisons between the Endeavor profiler and the Barrow soundings.
- Convective velocity scales will be calculated from the convective mixed layer height (z_{ic}), friction velocity ( ), and Monin-Obukhov length (*L*)
- The vertical potential temperature gradient above the convective boundary layer will be derived from the same data sets used for the convective mixed layer heights.
- Miscellaneous variables used by the AERMOD deposition algorithm (not used in the simulations):
  - Sensible heat fluxes will be set to the estimates from the COARE algorithm.
  - Relative humidity will be from the buoy observations
  - Bowen ratios will be calculated from the COARE predicted sensible and latent heat fluxes.
  - Albedo will be set to the COARE default of 0.055.
  - The cloud cover fraction will be from the Wainwright NWS observations.
  - Precipitation amount and code will be set as missing.
  - Surface pressure will be from the Wainwright or Pt. Lay observations

Table 1. Meteorological Preparation Summary

	2009 Ice Season	2009 Open Water	2010 Ice Season	2010 Open Water
Beaufort				
Wind Speed	Reindeer Island	Reindeer Island	Reindeer Island	Reindeer Island
Wind Direction	Reindeer Island	Reindeer Island	Reindeer Island	Reindeer Island
Temperature	Reindeer Island	Reindeer Island	Reindeer Island	Reindeer Island
Surface Flux	Solar-radiation, wind speed and ΔT from Reindeer Island	COARE based on Reindeer Island	Solar-radiation, wind speed and ΔT from Reindeer Island	COARE based on Reindeer Island
Air Sea ΔT	N/A	Reindeer Island Buoy (when available) and Sivulliq Buoy (when RI Buoy not available)	N/A	Reindeer Island Buoy (when available) and Sivulliq Buoy (when RI Buoy not available)
Mechanical Mix Ht.	AERMET u_* method based on Reindeer Island Data	AERMET u_* method based on Reindeer Island Data	AERMET u_* method based on Reindeer Island Data	AERMET u_* method based on Reindeer Island Data
Convective Mix Ht.	AERMET method based on Barrow Soundings	Algorithm based on analysis of concurrent 2010 Profiler and Barrow data	AERMET method based on Barrow Soundings	Endeavor Island Profiler
Chukchi				
Wind Speed	Wainwright	Burger Buoy (when available) and Reindeer Island Buoy/Sivulliq Buoy (when Burger Buoy not available)	Point Lay	Burger Buoy
Wind Direction	Wainwright	Burger Buoy (when available) and Wainwright NWS (when Burger Buoy not available)	Point Lay	Burger Buoy
Temperature	Wainwright	Burger Buoy (when available) and Reindeer Island Buoy/Sivulliq Buoy (when Burger Buoy not available)	Point Lay	Burger Buoy
Surface Flux	AERMET Method based on Wainwright NWS	COARE	Point Lay solar radiation, wind speed, ΔT	COARE

Table 1. Meteorological Preparation Summary

	2009 Ice Season	2009 Open Water	2010 Ice Season	2010 Open Water
	data			
Air Sea ΔT	N/A	Burger Buoy (when available) and Reindeer Island Buoy/Sivulliq Buoy (when Burger Buoy not available)	N/A	Burger Buoy
Mechanical Mix Ht.	AERMET u_* based on Wainwright Data	AERMET u_* based on Burger Buoy Data (or Reindeer Island Buoy/Sivulliq Buoy when Burger not available)	AERMET u_* based on Point Lay Data	AERMET u_* based on Burger Buoy
Convective Mix Ht.	AERMET method based on Barrow Soundings	Algorithm based on analysis of concurrent 2010 Profiler and Barrow data	AERMET method based on Barrow Soundings	Endeavor Island Profiler or algorithm based on analysis of concurrent 2010 Profiler and Barrow data

APPENDIX C

Measured NO_2/NOx Ratios for *Discoverer* Source

Stationary Source	Unit Description	Manufacturer or Vendor	Emission Unit Number	Size	Fuel Type	Combustor Equipment	Control Equipment	Data Source (CEM, Source Test)	Test Run	If Source Test, Load Level	Source or Test Year	NO2 PPMv	NO PPMv	NOx PPMv	NO2/NOx Ratio	Provided by
Discoverer	Generator Engine	Caterpillar D399	FD-5	1325 hp				Methods 1 - 4, 7E, 19	1	400 kW	2010	1	11.0	12.0	8.33%	*Emission Technologies, Inc.*
Discoverer	Generator Engine	Caterpillar D399	FD-5	1325 hp				Methods 1 - 4, 7E, 19	1	600 kW	2010	1	17.0	18.0	5.56%	*Emission Technologies, Inc.*
Discoverer	MLC Compressor	Caterpillar C-15	FD-9	540 hp				Methods 1 - 4, 7E, 19	1	50%	2010	65	169.6	234.6	27.71%	*Emission Technologies, Inc.*
Discoverer	MLC Compressor	Caterpillar C-15	FD-9	540 hp				Methods 1 - 4, 7E, 19	1	100%	2010	65	136.0	201.0	32.34%	*Emission Technologies, Inc.*
Discoverer	HPU Engine	Detroit 8V-71	FD-12	250 hp				Methods 1 - 4, 7E, 19	1	50%	2010	102	135.9	237.9	42.88%	*Emission Technologies, Inc.*
Discoverer	HPU Engine	Detroit 8V-71	FD-12	250 hp				Methods 1 - 4, 7E, 19	1	100%	2010	99	200.8	299.8	33.02%	*Emission Technologies, Inc.*
Discoverer	HPU Engine	Detroit 8V-71	FD-13	250 hp				Methods 1 - 4, 7E, 19	1	50%	2010	112	126.6	238.6	46.94%	*Emission Technologies, Inc.*
Discoverer	HPU Engine	Detroit 8V-71	FD-13	250 hp				Methods 1 - 4, 7E, 19	1	100%	2010	115	193.6	308.6	37.27%	*Emission Technologies, Inc.*
Discoverer	Starboard Deck Crane	Caterpillar D343	FD-15	365 hp				Methods 1 - 4, 7E, 19	1	60%	2010	90	490.0	580.0	15.52%	*Emission Technologies, Inc.*
Discoverer	Starboard Deck Crane	Caterpillar D343	FD-15	365 hp				Methods 1 - 4, 7E, 19	1	80%	2010	60	562.0	622.0	9.65%	*Emission Technologies, Inc.*
Discoverer	Cementing Unit	Detroit 8V-71N	FD-16	335 hp				Methods 1 - 4, 7E, 19	1	70%	2010	227	623.0	850.0	26.71%	*Emission Technologies, Inc.*
Discoverer	Cementing Unit	Detroit 8V-71N	FD-16	335 hp				Methods 1 - 4, 7E, 19	1	100%	2010	212	840.0	1,052.0	20.15%	*Emission Technologies, Inc.*
Discoverer	Cementing Unit	Detroit 8V-71N	FD-17	335 hp				Methods 1 - 4, 7E, 19	1	70%	2010	145	631.1	776.1	18.68%	*Emission Technologies, Inc.*
Discoverer	Cementing Unit	Detroit 8V-71N	FD-17	335 hp				Methods 1 - 4, 7E, 19	1	100%	2010	52	891.1	943.1	5.51%	*Emission Technologies, Inc.*
Discoverer	Logging Winch	Caterpillar C7	FD-19	250 hp				Methods 1 - 4, 7E, 19	1	50%	2010	25	124.8	149.8	16.69%	*Emission Technologies, Inc.*
Discoverer	Logging Winch	Caterpillar C7	FD-19	250 hp				Methods 1 - 4, 7E, 19	1	80%	2010	25	124.4	149.4	16.73%	*Emission Technologies, Inc.*
Discoverer	Logging Winch	Caterpillar C7	FD-19	250 hp				Methods 1 - 4, 7E, 19	1	50%	2010	25	123.8	148.8	16.80%	*Emission Technologies, Inc.*
Discoverer	Logging Winch	Caterpillar C7	FD-19	250 hp				Methods 1 - 4, 7E, 19	2	50%	2010	24	226.1	250.1	9.60%	*Emission Technologies, Inc.*
Discoverer	Logging Winch	Caterpillar C7	FD-19	250 hp				Methods 1 - 4, 7E, 19	3	50%	2010	20	152.0	172.0	11.63%	*Emission Technologies, Inc.*
Discoverer	Logging Winch	Caterpillar C7	FD-19	250 hp				Methods 1 - 4, 7E, 19	Average	50%	2010	23	167.3	190.3	12.68%	*Emission Technologies, Inc.*
Discoverer	Logging Winch	Caterpillar C7	FD-19	250 hp				Methods 1 - 4, 7E, 19	1	80%	2010	25	118.9	143.9	17.37%	*Emission Technologies, Inc.*
Discoverer	Logging Winch	Caterpillar C7	FD-19	250 hp				Methods 1 - 4, 7E, 19	2	80%	2010	27	121.6	148.6	18.17%	*Emission Technologies, Inc.*
Discoverer	Logging Winch	Caterpillar C7	FD-19	250 hp				Methods 1 - 4, 7E, 19	3	80%	2010	28	121.3	149.3	18.75%	*Emission Technologies, Inc.*
Discoverer	Logging Winch	Caterpillar C7	FD-19	250 hp				Methods 1 - 4, 7E, 19	Average	80%	2010	27	120.6	147.3	18.10%	*Emission Technologies, Inc.*
Discoverer	Heat Boiler	Clayton 200	FD-21	7.97 MMBtu/hr				Methods 1 - 4, 7E, 19	1	100%	2010	3	85.0	88.0	3.41%	*Emission Technologies, Inc.*
Discoverer	Heat Boiler	Clayton 200	FD-22	7.97 MMBtu/hr				Methods 1 - 4, 7E, 19	1	100%	2010	4	80.0	84.0	4.76%	*Emission Technologies, Inc.*
Discoverer	Incinerator	TeamTec GS500C	FD-23	276 lb/hr				Methods 1 - 4, 7E, 19	1	70 kg/hr	2010	0.25	10.8	11.0	2.27%	*Emission Technologies, Inc.*
Vladimir Ignatuk	Main Propulsion	Stork/8TM410	VI-1	5720 hp				Methods 1 - 4, 7E, 19	1	40%	2010	50	505.0	555.0	9.01%	*Emission Technologies, Inc.*
Vladimir Ignatuk	Main Propulsion	Stork/8TM410	VI-1	5720 hp				Methods 1 - 4, 7E, 19	1	60%	2010	60	600.0	660.0	9.09%	*Emission Technologies, Inc.*
Vladimir Ignatuk	Main Propulsion	Stork/8TM410	VI-1	5720 hp				Methods 1 - 4, 7E, 19	1	80%	2010	65	635.0	700.0	9.29%	*Emission Technologies, Inc.*
Vladimir Ignatuk	Main Propulsion	Stork/8TM410	VI-2	5720 hp				Methods 1 - 4, 7E, 19	1	40%	2010	36	405.0	441.0	8.16%	*Emission Technologies, Inc.*
Vladimir Ignatuk	Main Propulsion	Stork/8TM410	VI-2	5720 hp				Methods 1 - 4, 7E, 19	1	60%	2010	69	589.0	658.0	10.49%	*Emission Technologies, Inc.*
Vladimir Ignatuk	Main Propulsion	Stork/8TM410	VI-2	5720 hp				Methods 1 - 4, 7E, 19	1	80%	2010	98	607.0	705.0	13.90%	*Emission Technologies, Inc.*
Vladimir Ignatuk	Main Propulsion	Stork/8TM410	VI-3	5720 hp				Methods 1 - 4, 7E, 19	1	40%	2010	55	335.0	390.0	14.10%	*Emission Technologies, Inc.*
Vladimir Ignatuk	Main Propulsion	Stork/8TM410	VI-3	5720 hp				Methods 1 - 4, 7E, 19	1	60%	2010	75	642.0	717.0	10.46%	*Emission Technologies, Inc.*
Vladimir Ignatuk	Main Propulsion	Stork/8TM410	VI-3	5720 hp				Methods 1 - 4, 7E, 19	1	80%	2010	105	605.0	710.0	14.79%	*Emission Technologies, Inc.*
Vladimir Ignatuk	Main Propulsion	Stork/8TM410	VI-4	5720 hp				Methods 1 - 4, 7E, 19	1	40%	2010	63	475.0	538.0	11.71%	*Emission Technologies, Inc.*
Vladimir Ignatuk	Main Propulsion	Stork/8TM410	VI-4	5720 hp				Methods 1 - 4, 7E, 19	1	60%	2010	76	596.0	672.0	11.31%	*Emission Technologies, Inc.*
Vladimir Ignatuk	Main Propulsion	Stork/8TM410	VI-4	5720 hp				Methods 1 - 4, 7E, 19	1	80%	2010	95	655.0	750.0	12.67%	*Emission Technologies, Inc.*
Vladimir Ignatuk	Port Generator Engine 1	Caterpillar/D399PC	VI-5	750 kW				Methods 1 - 4, 7E, 19	1	325 kVA	2010	42	502.0	544.0	7.72%	*Emission Technologies, Inc.*
Vladimir Ignatuk	Port Generator Engine 1	Caterpillar/D399PC	VI-5	750 kW				Methods 1 - 4, 7E, 19	1	625 kVA	2010	35	598.0	633.0	5.53%	*Emission Technologies, Inc.*
Vladimir Ignatuk	Starboard Generator Engine 2	Caterpillar/D399PC	VI-6	750 kW				Methods 1 - 4, 7E, 19	1	325 kVA	2010	32	401.0	433.0	7.39%	*Emission Technologies, Inc.*
Vladimir Ignatuk	Starboard Generator Engine 2	Caterpillar/D399PC	VI-6	750 kW				Methods 1 - 4, 7E, 19	1	625 kVA	2010	44	492.0	536.0	8.21%	*Emission Technologies, Inc.*
Tor Viking II	Main Propulsion	MaK/6M32	TV-1	3784 hp				Methods 1 - 4, 7E, 19	1	30%	2010	9	60.0	69.0	13.04%	*Emission Technologies, Inc.*
Tor Viking II	Main Propulsion	MaK/6M32	TV-1	3784 hp				Methods 1 - 4, 7E, 19	1	40%	2010	6	64.0	70.0	8.57%	*Emission Technologies, Inc.*
Tor Viking II	Main Propulsion	MaK/6M32	TV-1	3784 hp				Methods 1 - 4, 7E, 19	1	60%	2010	9	165.0	174.0	5.17%	*Emission Technologies, Inc.*
Tor Viking II	Main Propulsion	MaK/6M32	TV-1	3784 hp				Methods 1 - 4, 7E, 19	1	80%	2010	10	226.0	236.0	4.24%	*Emission Technologies, Inc.*
Tor Viking II	Main Propulsion	MaK/8M32	TV-2	5046 hp				Methods 1 - 4, 7E, 19	1	30%	2010	4	81.0	85.0	4.71%	*Emission Technologies, Inc.*
Tor Viking II	Main Propulsion	MaK/8M32	TV-2	5046 hp				Methods 1 - 4, 7E, 19	1	40%	2010	29	282.0	310.8	9.27%	*Emission Technologies, Inc.*
Tor Viking II	Main Propulsion	MaK/8M32	TV-2	5046 hp				Methods 1 - 4, 7E, 19	1	60%	2010	12	150.0	162.0	7.41%	*Emission Technologies, Inc.*
Tor Viking II	Main Propulsion	MaK/8M32	TV-2	5046 hp				Methods 1 - 4, 7E, 19	1	80%	2010	14	218.0	232.0	6.03%	*Emission Technologies, Inc.*
Tor Viking II	Main Propulsion	MaK/8M32	TV-3	5046 hp				Methods 1 - 4, 7E, 19	1	30%	2010	4	54.0	58.0	6.90%	*Emission Technologies, Inc.*
Tor Viking II	Main Propulsion	MaK/8M32	TV-3	5046 hp				Methods 1 - 4, 7E, 19	1	40%	2010	4	56.0	60.0	6.67%	*Emission Technologies, Inc.*
Tor Viking II	Main Propulsion	MaK/8M32	TV-3	5046 hp				Methods 1 - 4, 7E, 19	1	60%	2010	8	146.0	154.0	5.19%	*Emission Technologies, Inc.*
Tor Viking II	Main Propulsion	MaK/8M32	TV-3	5046 hp				Methods 1 - 4, 7E, 19	1	80%	2010	24	274.0	298.0	8.05%	*Emission Technologies, Inc.*
Tor Viking II	Main Propulsion	MaK/6M32	TV-4	3784 hp				Methods 1 - 4, 7E, 19	1	30%	2010	15	122.0	137.0	10.95%	*Emission Technologies, Inc.*
Tor Viking II	Main Propulsion	MaK/6M32	TV-4	3784 hp				Methods 1 - 4, 7E, 19	1	40%	2010	5	66.0	71.0	7.04%	*Emission Technologies, Inc.*
Tor Viking II	Main Propulsion	MaK/6M32	TV-4	3784 hp				Methods 1 - 4, 7E, 19	1	60%	2010	18	95.0	113.0	15.93%	*Emission Technologies, Inc.*
Tor Viking II	Main Propulsion	MaK/6M32	TV-4	3784 hp				Methods 1 - 4, 7E, 19	1	80%	2010	10	166.0	176.0	5.68%	*Emission Technologies, Inc.*
Tor Viking II	Harbor Generator	Caterpillar/3412	TV-5	1168 hp				Methods 1 - 4, 7E, 19	1	50-60%	2010	30	239.0	269.0	11.15%	*Emission Technologies, Inc.*
Tor Viking II	Harbor Generator	Caterpillar/3412	TV-5	1168 hp				Methods 1 - 4, 7E, 19	1	90-100%	2010	24	344.0	368.0	6.52%	*Emission Technologies, Inc.*
Tor Viking II	Harbor Generator	Caterpillar/3412	TV-6	1168 hp				Methods 1 - 4, 7E, 19	1	50-60%	2010	40	172.0	212.0	18.87%	*Emission Technologies, Inc.*
Tor Viking II	Harbor Generator	Caterpillar/3412	TV-6	1168 hp				Methods 1 - 4, 7E, 19	1	90-100%	2010	38	348.0	386.0	9.84%	*Emission Technologies, Inc.*
Harvey Spirit 280	Port Main Engine	GE/7FDM12D5	HS-1	3070 hp				Methods 1 - 4, 7E, 19	1	30%	2010	131	1,356	1,487	8.81%	*Emission Technologies, Inc.*
Harvey Spirit 280	Port Main Engine	GE/7FDM12D5	HS-1	3070 hp				Methods 1 - 4, 7E, 19	1	60%	2010	113	1,356	1,469	7.69%	*Emission Technologies, Inc.*
Harvey Spirit 280	Port Main Engine	GE/7FDM12D5	HS-1	3070 hp				Methods 1 - 4, 7E, 19	1	80%	2010	91	915	1,006	9.05%	*Emission Technologies, Inc.*
Harvey Spirit 280	Starboard Main Engine	GE/7FDM12D5	HS-2	3070 hp				Methods 1 - 4, 7E, 19	1	60%	2010	95	986	1,081	8.79%	*Emission Technologies, Inc.*
Harvey Spirit 280	Starboard Main Engine	GE/7FDM12D5	HS-2	3070 hp				Methods 1 - 4, 7E, 19	1	80%	2010	47	795	842	5.58%	*Emission Technologies, Inc.*
Harvey Spirit 280	Starboard Generator Engine 1	Cummins/KTA19-D(M)	FD-31-HS-3	485 kW				Methods 1 - 4, 7E, 19	1	90-100%	2010	75	843	918	8.17%	*Emission Technologies, Inc.*
Harvey Spirit 280	Center Generator Engine 2	Cummins/KTA19-D(M)	FD-31-HS-4	485 kW				Methods 1 - 4, 7E, 19	1	90-100%	2010	61	899	960	6.35%	*Emission Technologies, Inc.*
Harvey Spirit 280	Port Generator Engine 3	Cummins/KTA19-D(M)	FD-31-HS-5	485 kW				Methods 1 - 4, 7E, 19	1	90-100%	2010	61	915	976	6.25%	*Emission Technologies, Inc.*

Stationary Source	Unit Description	Manufacturer or Vendor	Emission Unit Number	Size	Fuel Type	Combustor Equipment	Control Equipment	Data Source (CEM, Source Test)	Test Run	If Source Test, Load Level	Source or Test Year	NO2 PPMv	NO PPMv	NOx PPMv	NO2/NOx Ratio	Provided by
Harvey Explorer	Port Main Engine	Caterpillar/3516BDITA	HE-1	2260 hp				Methods 1 - 4, 7E, 19	1	35%	2010	82	908	990	8.28%	*Emission Technologies, Inc.*
Harvey Explorer	Port Main Engine	Caterpillar/3516BDITA	HE-1	2260 hp				Methods 1 - 4, 7E, 19	1	60%	2010	65	865	930	6.99%	*Emission Technologies, Inc.*
Harvey Explorer	Port Main Engine	Caterpillar/3516BDITA	HE-1	2260 hp				Methods 1 - 4, 7E, 19	1	85%	2010	74	831	905	8.18%	*Emission Technologies, Inc.*
Harvey Explorer	Starboard Generator 1	Caterpillar/3406CDITA	FD-31-HE-4	320 kW				Methods 1 - 4, 7E, 19	1	90-100%	2010	70	950	1,020	6.86%	*Emission Technologies, Inc.*
Harvey Explorer	Center Generator 2	Caterpillar/3406CDITA	FD-31-HE-4	320 kW				Methods 1 - 4, 7E, 19	1	90-100%	2010	56	881	937	5.98%	*Emission Technologies, Inc.*
Harvey Explorer	Port Generator 3	Caterpillar/3406CDITA	FD-31-HE-5	320 kW				Methods 1 - 4, 7E, 19	1	90-100%	2010	67	965	1,032	6.49%	*Emission Technologies, Inc.*
Harvey Explorer	Stern Thruster	Caterpillar/3412EDITA	HE-9	540 hp				Methods 1 - 4, 7E, 19	1	30%	2010	30	365	395	7.62%	*Emission Technologies, Inc.*
Harvey Explorer	Stern Thruster	Caterpillar/3412EDITA	HE-9	540 hp				Methods 1 - 4, 7E, 19	1	60%	2010	26	489	515	5.05%	*Emission Technologies, Inc.*
Harvey Explorer	Stern Thruster	Caterpillar/3412EDITA	HE-9	540 hp				Methods 1 - 4, 7E, 19	1	80%	2010	50	600	650	7.69%	*Emission Technologies, Inc.*
Nanuq	Port Main Engine	Caterpillar	N-1	2710 kW				Methods 1 - 4, 7E, 19	1	25%	2010	54	463.8	517.8	10.43%	*Emission Technologies, Inc.*
Nanuq	Port Main Engine	Caterpillar	N-1	2710 kW				Methods 1 - 4, 7E, 19	1	50%	2010	58	511.9	569.9	10.18%	*Emission Technologies, Inc.*
Nanuq	Port Main Engine	Caterpillar	N-1	2710 kW				Methods 1 - 4, 7E, 19	1	75%	2010	59	552.2	611.2	9.65%	*Emission Technologies, Inc.*
Nanuq	Port Main Engine	Caterpillar	N-1	2710 kW				Methods 1 - 4, 7E, 19	1	100%	2010	62	517.5	579.5	10.70%	*Emission Technologies, Inc.*
Nanuq	Starboard Main Engine	Caterpillar	N-2	2710 kW				Methods 1 - 4, 7E, 19	1	25%	2010	51	447.7	498.7	10.23%	*Emission Technologies, Inc.*
Nanuq	Starboard Main Engine	Caterpillar	N-2	2710 kW				Methods 1 - 4, 7E, 19	1	50%	2010	57	562.3	619.3	9.20%	*Emission Technologies, Inc.*
Nanuq	Starboard Main Engine	Caterpillar	N-2	2710 kW				Methods 1 - 4, 7E, 19	1	75%	2010	60	599.0	659.0	9.10%	*Emission Technologies, Inc.*
Nanuq	Starboard Main Engine	Caterpillar	N-2	2710 kW				Methods 1 - 4, 7E, 19	1	100%	2010	64	605.2	669.2	9.56%	*Emission Technologies, Inc.*
Nanuq	Aft Generator	Caterpillar	N-3	1285 hp				Methods 1 - 4, 7E, 19	1	50%	2010	40	500.4	540.4	7.40%	*Emission Technologies, Inc.*
Nanuq	Aft Generator	Caterpillar	N-3	1285 hp				Methods 1 - 4, 7E, 19	1	100%	2010	42	812.8	854.8	4.91%	*Emission Technologies, Inc.*
Nanuq	Forward Generator	Caterpillar	N-4	1285 hp				Methods 1 - 4, 7E, 19	1	50%	2010	39	497.0	536.0	7.28%	*Emission Technologies, Inc.*
Nanuq	Forward Generator	Caterpillar	N-4	1285 hp				Methods 1 - 4, 7E, 19	1	100%	2010	42	812.8	854.8	4.91%	*Emission Technologies, Inc.*