COUNTERMEASURES FOR THE BEAUFORT TRANSITION SEASON

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Abstract. Spring breakup and fall freeze-up in the Beaufort Sea present unique oil spill response challenges that are often addressed in theoretical terms. The literature, in fact, has repeated over the years a basis for selecting countermeasures that might not reflect actual field conditions. Unfortunately, this approach will not likely assist those tasked with planning and implementing a response operation. More helpful decision factors are proposed that focus on the issues that require clarification and the options that need to be very quickly considered. To this end, insights are provided into oil and ice conditions, spill containment and oil removal. This information should not only allow more practical and effective decisions to be made by first responders but may also result in applied research in the future that answers some much needed questions.

Keywords: arctic, ice, oil spill response

1. Introduction

My work since 1973 has focused on spill response equipment and techniques, often related to oil in ice. More recent projects have included assessments in 2001 and 2006 of the mechanical response capability on Alaska's North Slope for BP Exploration (Alaska) Inc., instruction in cold weather spills with Polaris Applied Sciences, Inc. and Alaska Clean Seas to Chevron's World-wide Response Team (Solsberg and Owens, 2001), and with Polaris and Environment Canada, the development of a Field Guide for Oil Spill Response in Arctic Waters (1998).

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From 1995 to 2000, I also participated in SINTEF's Mechanical Oil Removal in Ice Program (MORICE). In 2006, BP also requested a study of *in-situ* burning for dealing with oil releases in the Beaufort Sea during the transition seasons. Numerous other projects have included contingency planning, training, and the review of response options for oil spills in ice in the Canadian and US North as well as the North Caspian Sea and Sakhalin Island.

Most of this work has indicated that for both oil spill response planning and safe operations to effectively proceed, oil and ice behaviour in relation to each other requires a clear understanding. It is the one complex data set that determines how, and really if, an oil spill can be controlled. At no time is oil/ice movement more dynamic than during fall freeze-up and spring breakup in the Beaufort Sea. In this paper, various factors are addressed relevant to applying mechanical equipment and burning to spills during the transition seasons. Advances in equipment are briefly summarized as well as the parameters that affect burning. Perhaps the first step in making responsible decisions has not yet been fully taken. Oil/ice studies are therefore proposed to resolve these shortcomings. The studies should result in knowledge of direct benefit to contingency planners and first responders.

2. Oil/Ice Behaviour

Traditional views of oil and ice have largely been based on two or three-dimensional depictions, i.e., they consider the x, y and often z axes as shown in Figure 1.

The primary pathways that spilled oil takes on, under and within ice are well known. Oil can initially concentrate between floes and tends to form pockets in, under, and also ultimately as melt pools on ice that might mean its removal is possible. Nonetheless, if the dimension of time is added, this picture becomes a dynamic one, especially during the transition seasons which generally exist in the nearshore waters of the Beaufort Sea during June-July and September-October. The implications to spills and countermeasures are significant because of the changes that can be expected to occur in oil and ice during such periods:

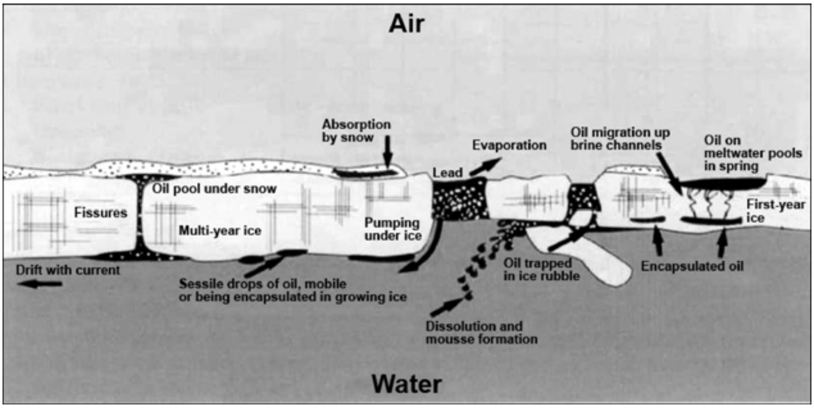


Figure 1. Oil behaviour in ice (Evers *et al.*, 2004).

- Ice size, shape, thickness, concentration and velocity are not static.
- Wind shifts in direction and speed are frequent.
- Wind largely determines ice position as well as oil trajectory.
- Oil spilled into ice will likely interact with it.
- The relative position of oil and ice will change over time.

The above factors require that first responders will have to make decisions much more quickly than they would for open water spills. This is because the conditions they plan for may change in a matter of hours (or less). Basic planning for response operations requires estimations of the extent of the ice cover and its characterization – the amount and type of ice present dictates what approach can be tried to control a spill and the safety precautions that must be taken. Mathematically modelling ice movement as it freezes or melts – and moves – is difficult and might not always be accurate. It will not likely contribute to improving either planning or engaging in an actual response.

When numerous floes are present with relatively few areas of open water that together can span distances of several kilometers, there is generally little doubt about ice cover – at between 90% and 100%, the ice cover can be readily estimated. Should a spill occur in such conditions, this still requires characterizing the oil in terms of its volume, thickness, viscosity, etc. Nonetheless, as the ice cover diminishes, assessments are not as easy for a number of reasons (see Figure 2):

Figure 2. Estimating ice cover is not an exact science.

- The observer's position determines oil/ice reporting numbers and can depend on height and distance; several different vantage points are necessary.
- Submerged ice and ice with sediment on it will reduce estimates of ice cover – not all of the ice that might affect the response will be visible.
- Oil might initially concentrate at an ice "edge".
- An ice "edge" might consist of a series of floes that will vary greatly in configuration and extend from only several metres to much longer distances.
- Oil will likely accumulate in small and large pockets.
- The ice can be expected to move with the spilled oil and form many small pools that change in character and move relative to each other as winds blow the oil/ice first in one direction and then another.

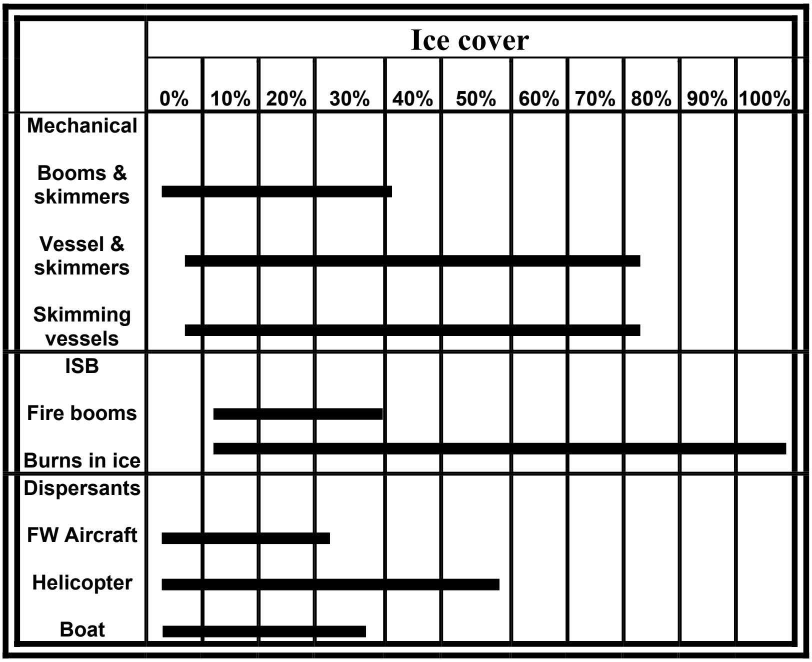
What we do know is that the spilled oil, if present in sufficient quantities, will likely initially collect in embayments and smaller pockets along the ice edges where it would be more amenable to removal. This is partially because oil and water appear to move more quickly than ice floes with oil slicks advected by winds of 5–10 km/h or more against the ice. Oil/ice tracking using spill simulators and ice tracking buoys will likely be of more use than mathematical modeling to determine trajectories – but applied studies are lacking. During a spill, airboats and aerial observation platforms, especially helicopters, will provide the key means to determine where the oil is relative to the ice, in what quantities, and if, and by what means, responders can remove it. In some cases, when oil has been released and has widely dispersed as fine droplets and/or the ice is present as very small pieces, or brash ice, no response measure may be practical. Whatever the circumstances, safety of operations will be, of course, the highest priority.

3. Countermeasures for Oil in Ice

The response to oil spills in ice has been widely studied since the 1970s. A common way of presenting the potential use of countermeasures in Arctic conditions is a chart or table that assigns the standard approaches of mechanical operations, *in-situ* burning and dispersant application to a specific range of ice cover (Table 1). The problem with this approach, however, is that conditions in Beaufort Sea ice are so dynamic during the transition seasons that any response would likely prove to be limited to a small (time) window of opportunity – leave alone the obvious safety concerns. The same can be said for dealing with oil in moving ice in other parts of the world.

While specific ice cover limits for countermeasures are not exact, nor is precision always needed or applicable, what becomes apparent when in actual field conditions, is the utility of either platforms that can work at ice edges or a means to control spills using aerial methods. In either case, however accomplished, working outside of the collections of ice floes affords more opportunity for oil removal. To this end, burning oil appears to be the most practical response option with the widest range of possible application. Still, questions relating to any countermeasures for oil in ice point to the need to further understand ice drift and oil movement (so that we determine if oil is in fact going to be amenable to removal) as well as to the need to conduct applied studies of the various spill response technologies (to see what really works). There are existing sources of information that can help as regards the latter.

TABLE 1. Countermeasures for oil in ice.



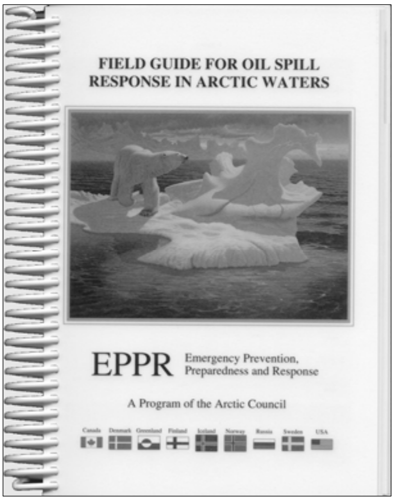


Figure 3. Field Guide for Oil Spill Response in Arctic Waters (Owens *et al.*, 1998).

3.1. A FIELD GUIDE FOR OIL SPILL RESPONSE IN ARCTIC WATERS

A *Field Guide for Oil Spill Response in Arctic Waters* (Owens *et al.*, 1998) (Figure 3) was completed for the eight-nation Emergency Prevention, Preparedness and Response (EPPR) Working Group. The *Field Guide* is intended for use by the circumpolar countries to facilitate oil spill sresponse for seas, lakes, rivers, and shorelines. It addresses the unique climatic and physiographic features of the Arctic environment. Practical information is presented for technical managers and decision makers as well as local community first responders. The *Field Guide* does not duplicate existing manuals and documents, but rather, collates available information on the behaviour of, and response to, oil in ice and snow conditions.

"Part A" of the *Field Guide* is comprised of three key operational sections that can be used independently:

1. **A field guide for first responders** based on seasonal conditions that focuses on practical actions that can be taken to control the spread of oil and minimize its effects
2. **Response strategies** described in the context of source control, control of free oil, protection, and shoreline treatment and
3. **Response methods** for on water, in ice, and shoreline treatment.

"Part B" of the *Field Guide* contains technical support information basic to understanding the Arctic environment and to developing an effective response. It addresses the **behaviour and fate** of spilled oil and the **notification and decision processes** associated with managing a response operation. A final section summarizes the **coastal character** of each Arctic geographic region.

The *Field Guide* presents practical information in an original style and format. For example, bullets and icons are used throughout the *Field Guide* because they can be recognized internationally, regardless of language. General approaches are presented rather than the technical specifications or details of equipment and methods, e.g., those being researched via MORICE.

While very comprehensive, the limitations of the *Field Guide* are similar to those of other references. Response options for the transition seasons are generally well indicated for oil in ice but the details of oil movement in relation to ice drift and the need for quick decisions are not fully discussed. It is these aspects, as well as technology updates, that would add to the extent and practicality of the information that has been compiled. The versatility of burning oil in ice is very apparent when consulting countermeasures options in the *Field Guide.*

3.2. BEST AVAILABLE TECHNOLOGY (BAT) ANALYSES

Best Available Technology (BAT) analyses were conducted in 2001 and 2006 on behalf of BP Exploration (Alaska) Inc. for mechanical oil spill response equipment in North Slope marine ice during the transition seasons following regulations developed by the Alaska Department of Environmental Conservation (ADEC). The eight BAT criteria are as follows (Solsberg *et al.*, 2002):

1. **Availability**

   Is the technology alternative being considered the best in use in other similar situations and is it available for use by the applicant? Consider technologies used in other industries world-wide.

2. **Transferability**

   Is the technology alternative being considered transferable to the applicant's operations? Is it applicable to this situation?

3. **Effectiveness**

   Is there reasonable expectation that each technology will provide increased spill prevention or other environmental benefits? In this context, will the technology be more effective in containing a discharge and decreasing impacts to air and water.

4. **Cost**

   What is the cost to the applicant of best available technology, including its cost relative to remaining years of service of currently used equipment?

5. **Age and condition**

   What is the age/condition of existing versus available technologies.

6. **Compatibility**

   Is each technology compatible with existing operations and technologies?

7. **Feasibility**

   Is it feasible to use a particular device/system, technically and operationally?

8. **Environmental impacts**

   Will impacts to air, land, and water offset any environmental benefits?

Three analyses of response equipment were conducted for each freeze-up and breakup in which the eight BAT criteria were applied to (1) commercially available spill technologies, (2) a limited number of devices not yet generally available, and (3) additional promising technologies. MORICE equipment was reviewed (from SINTEF's Mechanical Recovery of Oil in Ice program), as well as other concepts (primarily from Lamor Corporation Ab of Finland) specifically developed for the recovery of oil in ice.

Equipment studied included at least three each of small and large booms, skimmers and pumps as well as various vessels and barges. Vessel-skimmer-boom containment-and-recovery systems were also examined for use in ice near the Realistic Maximum Response Operating Limitations (RMROLs). U-boom and various skimmer systems were also evaluated for their operation in narrow leads and in ice fields. Skimming systems independent of booms were also studied.

Where equipment capability varies as a function of oil properties, then this distinction was made. For example, oil thickness and footprint differs between batch spills and blowout oil deposited as droplets. In addition, the degree of oil weathering, icing problems, and the operation of ancillaries (e.g., scrapers, combs, wringers) as these might affect performance were factored into the evaluations.

It is important to note that the BAT reviews utilize a methodology that could be applied by other organizations to evaluate and document realistic oil-in-ice response capabilities, including equipment and strategies, for operators, regulators and stakeholders. BAT also provides a sound basis to determine R&D needs since limitations become evident from a number of different perspectives.

3.3. RESULTS OF RESPONSE EQUIPMENT REVIEWS

Large, heavy-duty booms are commercially available that have a proven record in harsh offshore environments, excellent stability, and design features suitable for potential use in ice infestations. Their limitations in ice include disruption of the oil-ice mixture, possible damage, and inaccessibility of skimmers to the oil or their inability to process the oil/ice mixture presented by the boom.

Small containment booms are more suited to open water response operations than to operations in ice. BAT, in terms of a small booms could consider however, boom dimensions, and fabric details (e.g., tensile and tear strength, cold crack temperature, flexibility, crush-resistant flotation, fittings, etc.)

Many large high volume pumps are available that are suited for transferring fresh and emulsified crude oil from tanks but were not designed to move slush ice and oil. Enhancement of screw auger pumps (Figure 4) using steam/heat and annular flow is now considered to be available technology (Cooper, 2004). Advances made over the past several years have been significant. While such pumps incorporate components that have been improved for processing debris and viscous

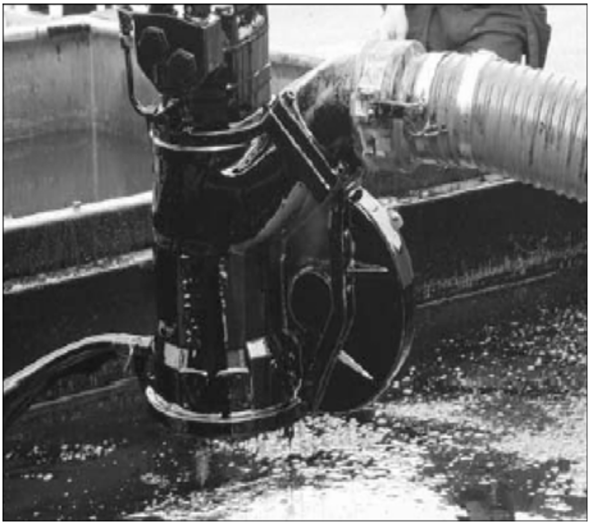


Figure 4. Screw auger pump.

Figure 5. Brush drum on arm.

oil (e.g., multiple cutting knives, split casing, redundant sealing discs, and Teflon-impregnated metal) they still can encounter problems transferring slush and small ice pieces at sub-freezing temperatures.

Various small pumps were considered to be BAT that have potential application to skimming and general transfer duties for water, oil and small ice forms. Eliminating elbows, indirect feed, limiting exposure to sub-freezing temperatures before use, draining between uses, complete contact of electrical connections, etc., contribute to good pumping capability. Still, there are many problems present when small pumps are used in winter conditions.

For operation during freeze-up and breakup on the North Slope, the barges Arctic Endeavor and Beaufort 20 are well suited for their assigned tasks. Similarly, the ACS Bay Boats are considered to be Best Available Technology suitable for available response equipment and its capabilities.

In a continuous ice cover, the brush drum, brush adaptors and brush pack skimmers comprise the best choices for dealing with oil spills, but still have limited capability. Not all oil present will likely be removed. The brush drum skimmers attached to a hydraulic arm (Figure 5) can be readily positioned in oil in ice, operated there, and then lifted out and moved elsewhere as needed. These skimmers should be supplemented with other options including vertical mop and weir skimmers that could be used when *stationary* oil collection is possible in ice that does not significantly affect their performance.

Their advantage is that ice pieces are processed under the recovery device so that ice does not clog the system. However, there is a loss of some of the oil as it passes under the device along with the ice. During freeze-up, it is expected that the drum brush might marginally increase the ice concentration that an oil recovery system could function in, but would miss oil as it processes ice. Lamor Corporation Ab manufactures brush belts and adapters (Figures 6 and 7).

Even with the advances that have been made recently with skimmers and their ability to process small ice pieces, the challenges that remain for mechanically removing oil from moving ice can be summarized as follows:

Figure 6. Brush belt.

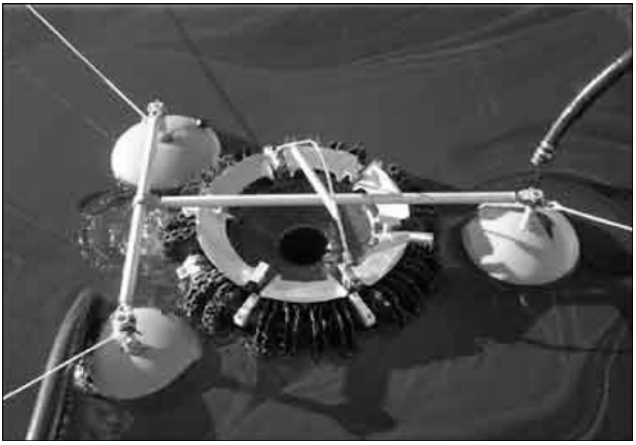


Figure 7. Brush adaptor.

- Limited access to oil
- Reduced oil flow to the skimmer
- Icing/freezing/jamming of equipment
- Separation of oil from ice
- Contamination/cleaning of ice
- Deflection of oil together with ice
- Strength and durability considerations
- Detection, monitoring of slick.

Applying multiple smaller skimmers in ice might be possible if air temperature is above freezing and if there is access to discrete pockets of oil. Slick thickness should be about 2.5 cm (1 in.) for significant recovery for blowouts or batch releases that have been previously contained by booms and/or ice.

The other primary approach to skimming oil in ice has evolved into advancing concepts that either raise ice pieces (MORICE) or that deflect them downward (Jensen *et al.*, 2002; Jensen and Solsberg, 2001). Oil is then separated and collected. In the case of MORICE, the oil is washed off ice that passes over a grated belt and is picked up by rotating brush drums while Lamor's Oil Ice Separator (LOIS) features a vibrating grate that deflects ice downward and then recovers oil via a brush pack (Figures 8, 9 and 10).

Figure 8. Testing in oil/ice.

Figure 9. MORICE.

Figure 10. Lamor LOIS.

Both the MORICE and LOIS approaches are predicated on the following scenario:

- Ice pieces 0 to 2–3 m ice size (*not* large floes)
- Sixty to 70% ice concentration on large scale, locally up to 100%
- Brash and slush ice present
- Moderate dynamic conditions (waves, wind, current).

There might be specific situations where mechanical systems should be further investigated; however, many systems have potential limitations related to ice processing problems, air temperature (freezing), or overall practicality and effectiveness in moving transition season ice:

- Various rope mop configurations
- Air and water jets to deflect oil under ice
- Improvements to Transrec (including an Arctic model)
- Ice boom to manage ice – and perhaps oil
- Continued work on augers (as a component of other systems)
- Various processing equipment (from other applications, e.g., mining).

Figure 11. LAS skimmer.

Lamor Corporation (2006) has developed several iterations of a device that now incorporates components that have much greater potential for collecting oil, albeit in a stationary mode. Lamor's Arctic Skimmer (LAS) (Figure 11) utilizes two brush wheels that rotate in the same direction as water flow to force oil under water. The water flows out holes at the back of the skimmer while the oil adheres to the brushes and enters a hopper. Screws in the hopper crush ice pieces and feed oil, ice and slush to a built-in screw auger pump.

3.4. *IN-SITU* BURNING

Because oil can be removed using a Helitorch (Figure 12), *in-situ* burning comprises a response option that can be quickly and safely implemented for a variety of ice conditions (Fingas and Punt, 2000). The oil must still be present in a burnable state and quantities but a much wider range of ice cover can be addressed that will not interfere with operations as they would with mechanical methods.

Figure 12. Helitorch.

While fire booms might not always have application as ice cover increases, similar to their conventional open water counterparts, the concentrating and holding effects of ice floes could make burning feasible. Again, the relative behaviour of spilled oil and ice require further investigation to determine how feasible it is, in fact, to burn oil during the transition seasons in dynamic ice. Demuslifiers and herders have been studied with some degree of potential success in this regard. However, this work has been conducted in smaller scale tests where edge effects and other factors might result in burns that would not otherwise occur. While small and meso-scale testing is needed, field work is the ultimate means of measuring the feasibility of burning.

The key questions that arise when considering burning oil in an ice environment relate to the following issues:

- Dealing with the quickly changing oil and ice conditions of the Beaufort Sea during breakup and freeze-up.
- Determining the location, amount, burnability of oil (API gravity, oil thickness, % water in the oil – emulsification, weight % distribution).

- Ability to quickly deploy personnel and resources on sufficient scale so as to result in significant oil removal rates.
- The most effective means of utilizing the Helitorch and perhaps modifying it and locating burnable quantities of oil during a sortie.
- Determining the nature of the residue as to whether it floats or sinks and its potential impacts? (Net Environmental Benefit Analysis).
- Investigating the effects of ice type on burn, especially in terms of smaller formats such as frazil, brash, etc.
- Assessing in field conditions the practicality of applying firebooms, demulsifiers and herders.
- Safety of operations.

4. Conclusions

The conclusions and recommendations that can be derived from the various projects conducted for oil-in-ice since 1990, particularly for the transition seasons in the Beaufort Sea, can be summarized as the following R&D and response priorities:

- Study the tracking of oil movement relative to ice drift by engaging in field work using spill simulators and tracking buoys if actual oil cannot be used.
- Select response tactics that may be effective for short periods based on field observations that utilize various vantage points.
- Plan for the quick implementation of countermeasures at strategic locations that might only be effective for several hours at a time.
- Focus on responder needs that accurate field information yields and not generalized applications indicated by charts and test tank data found in the literature.
- *In-situ* burning is likely the key oil removal method and requires further study of aerial application methods and oil/ice movement so that even higher efficiencies might result.
- Know details of oil and ice interactions and effects on spills for specific geographic locations when planning response operations.
- SAFETY of operations is the Number One Priority.

5. Acknowledgements

Alaska Clean Seas, SINTEF, Lamor Corporation Ab and BP Exploration (Alaska) Inc. are acknowledged for the insights that project work and discussions with company personnel have provided. Various operational issues related to using equipment in cold weather and modifications that the organizations had considered were discussed. Equipment manufacturers supplied technical specifications and test data as requested. In the 2001 work for BP, ADEC clarified BAT requirements and requested additional information that resulted in further insights into steam enhancement, the use of pumps and large booms, and the potential application of specific skimmer systems.

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