The Newfoundland Offshore Burn Experiment - NOBE Experimental Design and Overview

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Summary

A group of over 25 agencies from Canada and the United States conducted a major offshore burn near Newfoundland, Canada. Two lots of oil, about 50 tons each, were released into a fire-proof boom. Each burn lasted over an hour and was monitored for emissions and physical parameters. Over 200 sensors or samplers were employed to yield data on over 2000 parameters or substances. The experiment was the largest of its type ever conducted. The operation was extensive, over 20 vessels, 7 aircraft and 230 people were involved in the at-sea operation.

The experiment resulted in extensive analytical data as well as significant operational data, some of which are presented here.

Background and Rationale

Several recent large accidental oil spills have confirmed that oil that contaminated shorelines causes extensive environmental damage and results in very high cleanup costs. Perhaps much of the spilled oil could have been burned *in situ* without igniting the oil remaining in the vessels.

Ten years of intensive laboratory and tank testing on the *in situ* combustion of oil have indicated that the nature and concentrations of atmospheric emissions from *in situ* burning of oil offshore will normally be an acceptable tradeoff when weighed against the environmental risks and cleanup costs of nearshore and shoreline contamination.

Sponsors of NOBE
(In order of funding level)
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Environment Canada. Arctic and Marine Oil Spill Program (AMOP) Technical Seminar, 17th Proceedings. Volume 2. June 8-10, 1994, Vancouver, British Columbia, Environment Canada, Ottawa, Ontario, 1053-1063 pp, 1994.

Analyses conducted to date have shown that the high temperatures reached during efficient *in situ* combustion results in relatively complete destruction of the oil. Fire resistant containment booms developed over the past few years offer the potential, under suitable wind and sea conditions, to both maintain oil at a suitable thickness for burning at sea and contain undesired spreading of the oil and the fire.

Further, based on small- and mid-scale experiments, in combination with our knowledge of basic physical processes, numerical models continue to be developed to predict heat transfer, the generation of airborne pollutants and the weight of residue produced from the combustion of oil on water.

Based on the current state of knowledge regarding burning as an oil spill countermeasure, the next logical extension of the technology was the controlled experimental release and burning of oil under realistic full-scale field conditions. Such an experiment, designed according to the most rigorous scientific protocols, would allow the identification and quantification of the chemical species associated with and generated by the burning of oil on the open ocean (particularly smoke and gaseous emissions). These compounds have not been adequately characterized and never quantified, making it difficult if not impossible to estimate environmental risk. An experiment of this type would also allow the verification of theoretical numerical models that have been developed to predict the content and trajectories of smoke plumes.

This experiment would also provide the necessary information for regulatory agencies to consider pre-approval for large scale burns under emergency spill conditions (an essential element in making effective use of burning in a field situation). An equally important benefit would involve the development of response protocols that will guide oil industry, spill cooperatives, and government regulatory personnel in the safe and effective application of burning in future spills.

Objectives

The experiment was designed to meet four primary objectives:

1. To obtain measurements of critical burn parameters and to collect and analyze chemical emissions needed for comparison with data sets and models that are currently based on laboratory and medium scale tests.
2. To obtain samples for analysis of the smoke plume, water, and gaseous emissions needed to determine whether the environmental impact of burning is acceptable.
3. To conduct a large scale oil burning experiment in realistic open ocean conditions to demonstrate contained burning as a spill response technique.
4. To develop a response protocol that will establish operational strategies for burning and safety procedures under a variety of environmental and operational conditions.

Operational Details and Plans

The Newfoundland Burn Experiment took place on the Grand Banks in a 34-km^2 (ca. 10 nmi^2) area, coordinates 47° 40' N, 52° W. The location is about 42 km (25 nmi) east of the port of St. John's, Newfoundland. The experiment was conducted on August 12, 1993. The time and place were chosen to minimize ecological damage and interference with the fishery. The wide weather window (10 days) was chosen to maximize the chance of favourable weather and sea state conditions. Two replicate experiments were planned wherein 50 m^3 (13,200 gal) of oil was to be discharged in a controlled manner into a fire-proof boom and ignited. The actual amount discharged was slightly less than this.

A sophisticated array of state-of-the-art sensing, sampling and data-gathering equipment was deployed from a variety of platforms. The layout of the vessels for the experiment is shown in Figure 1. Sampling near the fire and in the smoke plume was conducted from remote-controlled boats, helicopters and an ROV (submersible) that were deployed beneath the slick. At more distant locations, a tethered blimp, conventional helicopters, fixed-wing aircraft and a variety of vessels were used. As a contingency measure, a secondary oil containment boom and recovery system capable of picking up all the oil that was discharged was towed behind the fire boom.

The experiment involved the measurement of (1) emissions to the air, (2) levels of oil and related compounds in the water, and (3) operational parameters relevant to *in situ* burning. Data was collected and analyzed to generate information on over 2000 parameters.

The vessel configuration for the experiment is shown in Figure 1. The procession was led by the 224' CCG vessel *Sir Wilfred Grenfell* (hereafter referred to as the *Grenfell)* that served as the supply and oil discharge vessel. The fire boom was towed directly behind the *Grenfell* by two Boston Whalers with 150-ft tow lines. Two, 14-ft remote controlled boats, and a 36-ft sea truck serving as a platform for the tethered blimp, were approximately 50, 100 and 150 m, respectively, behind the apex of the fire boom. One hundred metres behind the sea truck, the secondary containment boom was towed by two, 46-ft vessels (i.e. 250 m behind the fire boom).

A number of other vessels were stationed farther from the main procession. These included several Boston Whalers from which routine sampling was conducted and other vessels that served as platforms from which the remote controlled boats, remote controlled helicopters and the ROV were operated. The command vessel was the 272-ft CCG vessel *Ann Harvey*. Two 100-ft vessels were chartered to accommodate scientific observers and visitors.

The oil was released into a fire-resistant boom and burned within it. Air emissions were monitored downwind using two remote-controlled boats, a research vessel and from an airplane. The plume itself was sampled by two remote-controlled helicopters and a blimp. Water samples were collected from the remote-controlled sampling boats, and air and water temperatures measured from the same vessels. The fire-resistant boom was equipped with thermocouples to monitor temperatures directly impacting it and those in the water directly underneath the fire. A submersible was deployed under the burning slick to monitor temperatures and take video footage. A small boat monitored and measured surface material that escaped and took samples of the burn residue after the burn.

The oil was released from a supply-type ship through a skimmer so that if there were some problem, the flow could be reversed and the oil recovered. A 700-foot section of boom was used. The amount of oil released in each spill was 50 cubic metres or about 10,000 Imperial gallons. This is about the lower limit of a typical boom capacity. Once sufficient oil was in the boom to sustain combustion, it was ignited using a Helitorch.

The fire-resistant boom used was a commercial version along with some experimental sections. The middle sections near the burn were equipped with a number of thermocouples to measure the temperature on the boom. The boom was backed up by another boom, an offshore type, about one kilometre down current. This second boom was loaded with sorbent to ensure that any sheen was recovered. The fire-resistant boom was towed by a major vessel and the opening was maintained by two vessels towing

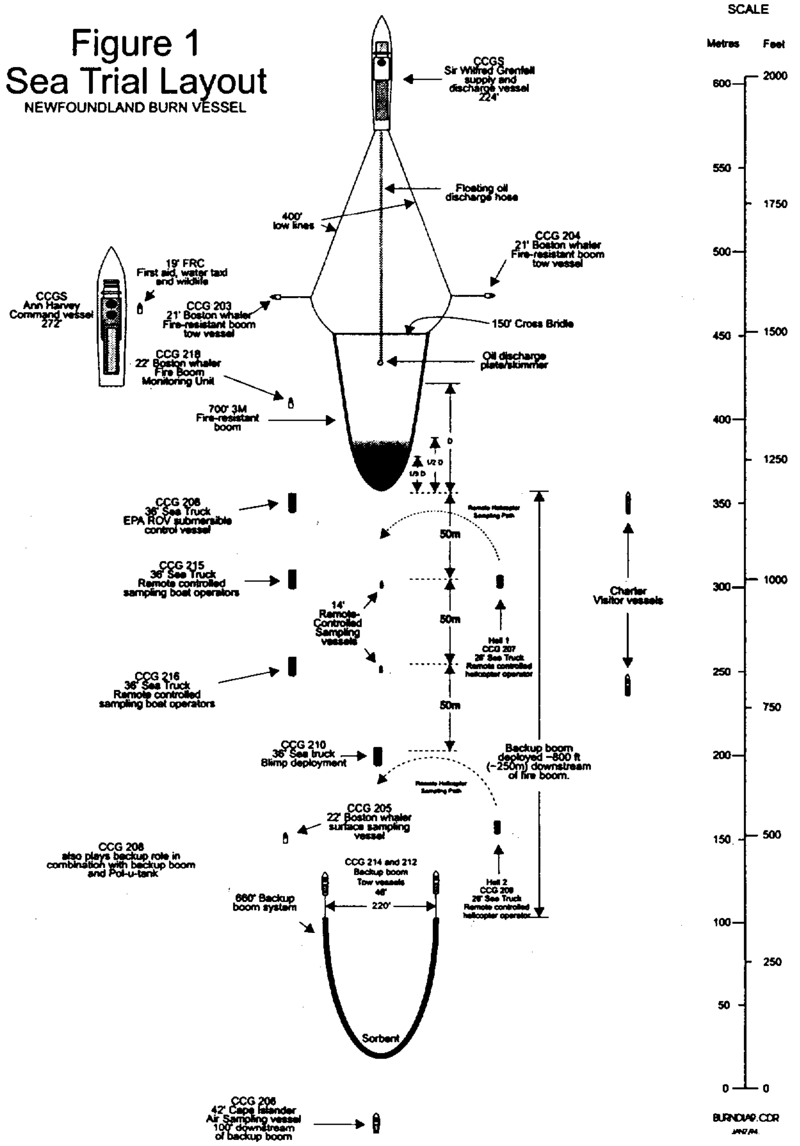


Figure 1
Sea Trial Layout
NEWFOUNDLAND BURN VESSEL

outward at an angle of approximately 45 degrees. Tow vessels were equipped with current meters to ensure that they are able to maintain a forward speed of 0.5 knots.

Command and control operations took place from a major vessel of the Canadian Coast Guard, the ANN HARVEY. One helicopter was used both to ignite the slick and put out flares to guide the procession into the wind. Another helicopter was used to provide still and video footage for documentation. Two charter ships were engaged to bring out observers. They were also used as platforms for some of the documentation and air measurement. Several smaller boats were used for other sampling purposes and for controlling the remote sampling boats and a remote-underwater vessel.

OPERATIONAL RESULTS -

Burn one started after a second Helitorch run. Reports from the helicopters and both airplanes indicated that the smoke plume bifurcated after about 2 km downwind. A small part remained with the inversion layer at about 0.5 km and the main portion split with one portion turning southeast and one turning east after rising about 2 km. The pumping during burn 1 had to be stopped several times because the fire often spread back to the discharge point. The average discharge and burn rate for burn 1 were 915 L/min. The fire-resistant boom was inspected after the first burn. Some signs of fatigue in the stainless steel core were observed at a point about 10 cm from the stiffeners. Some of the Nextel fire-resistant fabric was missing from these areas as well. The boom was still fit for another burn.

Table 1 - Burn Summary

Burn 1

Oil volume discharged - 48.3 m^3
Burn and Pump time - 1.5 hours
Residue in fireproof boom - 0.2 m^3 (max.)
Residue in backup boom - 0.2 m^3 (max.)
Efficiency - >99%

Burn 2

Oil volume discharged - 28.9 m^3
Burn and Pump time - 1.3 hours
Residue in fireproof boom - 0.1 m^3 (max.)
Residue in backup boom - 0.3 m^3 (max.)
Efficiency - >99%

The crews re-fit the equipment for the second burn which began in mid-afternoon. The first run of the Helitorch ignited the oil. Some oil was again splashed over, however, unlike the first burn no sheening whatsoever was observed. The oil outside of the boom burned completely leaving only small patches of residue which drifted back into the secondary recovery boom. The wind was 8 to 11 km/hr and this resulted in an approximate 45 degree angle for the plume. This burn was characterized by its "classical", regular plume behaviour. The plume did, however, bifurcate about 2 km downwind, similar to the previous plume.

The pump rate for this burn averaged 610 L/min. Pumping was stopped after 1 1/4 hours of burn time when some small pieces of the fire-resistant boom were released. The duration had already exceeded planned sampling times and most samplers had already been stopped.

The fire-resistant boom was again inspected for damage and it was found that a prototype section with a middle tension member had lost three of its float logs. Inspection of this section at the factory showed that the section had not been properly constructed. The apex of the boom was still holding oil. The boom was in generally good condition, but one would not have used the apex for another burn.

SAMPLING

Sampling methodologies and target emissions are summarized in Table 2. Detailed methods are described in the literature. [1]

Table 2 **Summary of Analytical Methods**

Sample Taken	Sampler	Measurement Parameter	Secondary Parameters	Additional Parameters
Soot at Sea Level	High Volume Sampler	Dioxinsand Dibenzofurans	Particulates	PAHs
	Sampling Pump medium volume	PAHs	Particulates	
	RAM	Particulates		
	Cascade sampler	Particle size	PAHs	
Soot in Smoke	Sampling Pump low volume	PAHs	Particulates	Metals
	blimp, remote-controlled helicopter, research aircraft			
Gases	Summa Canister	Volatile Organic Compounds	CO_2	
	Sampling Pump low volume	Volatile Organic Compounds		
	CO_2 Meter	Carbon Dioxide		
	SO_2 Meter	Sulphur Dioxide		
	NO_2 Meter	Nitrogen Dioxide		
	CO Meter	Carbon Monoxide		
Oil		PAHs	Metals	Full Analysis
Burn Residue		PAHs	Metals	Full Analysis
Water Under Burn		PAHs	Organics	Toxicity

FINDINGS

Oil and Basic Operations

The basic data on the operations and oil pumping are summarized in Tables 3 and 4. The speed at which the fire boom and the procession moved was calibrated by using a current meter behind the fire boom. The data from the current meter are summarized in Figure 2. The cables towing the fire boom were monitored using strain gauges. The output is illustrated in Figure 3. This is a very complex pattern, however, if de-convoluted to remove head wind gusts, sea currents and waves, would appear to be a more constant force. Analysis on this is still proceeding.

Table 3

TIMING AND OIL FLOW for BURN # 1

TIMING	Actual time (hh:mm)	Standardized time (min)	Burn period %	Load (kg)	Current Meter (on CCG 218)	Towing Speed (Boston Whaler)	Oil FLow (L/min)	Total Oil Volume (L)
Background	taken before Aug 12, 93				0.21<0.57<0.91*			
Background	before 9:30 on Aug 12, 93 (before oil is released)							
Pre-ignition	9:30 to 10:30 (oil on water)	-60		76.1			265<908<1166	
Ignition time	10:30	0						
Early burn	10:30 to 10:53	24	0 to 25					
Midway Point	11:17	47	50					
Middle burn	10:54 to 11:40	24 to 70	25 to 75					
Late burn	11:41 to 12:04	70 to 94	75 to 100					
End of Burn	12:04		100					48260
Burn period	10:30 to 12:04	94	0 to 100	60.2			115<872<1190	
Post-burn	12:04 to 13:00 (residue collection period)			22.7				
Post residue collection period	overlaps Burn 2 background and evaporation period							

* all values presented as min<average>maximum whenever there is a large range

Table 4

TIMING AND OIL FLOW for BURN # 2

TIMING	Actual time (hh:mm)	Standardized time (min)	Burn period %	Load (kg)	Current Meter (on CCG 218)	Towing Speed (Boston Whaler)	Oil FLow (L/min)	Total Oil Volume (L)
Background	N/A							
Background	13:00 to 13:52 (before oil is release)			28.1	N/A			
Pre-ignition	13:52 to 14:06 (oil on water)	-14		31.6			243<708<903*	
Ignition time	14:06	0						
Early burn	14:06 to 14:24	0 to 18	0 to 25					
Midway Point	14:42	36.5	50					
Middle burn	14:24 to 15:00	18 to 55	25 to 75					
Late burn	15:00 to 15:19	55 to 73	75 to 100					
End of Burn	15:19	73	100					25900
Burn period	14:06 to 15:19	73	0 to 100	15.3			159<578<845	
Post-burn	15:19 to 16:30 (residue collection period)			2.5				
Post residue collection period	16:30 to as long as 2 days later							

* all values presented as min<average>maximum whenever there is a large range

Figure 2 Forward motion for Pre-Burn 1 (current meter on CCG 216)

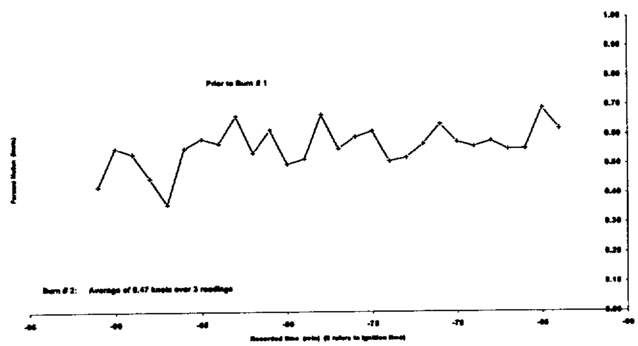
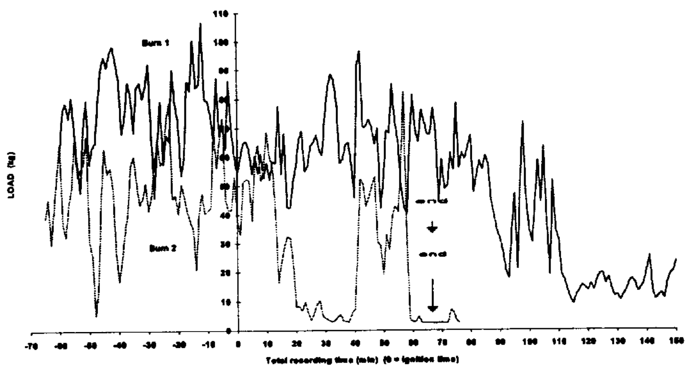


Figure 3 Average Load on Fireboom per minute



The oil discharge was monitored with a flow meter and electronically recorded. The flows are shown in Figures 4 and 5. Flow had to be stopped on occasion to avoid loss over the top of the booms.

Figure 4 Oil Flow for Burn 1

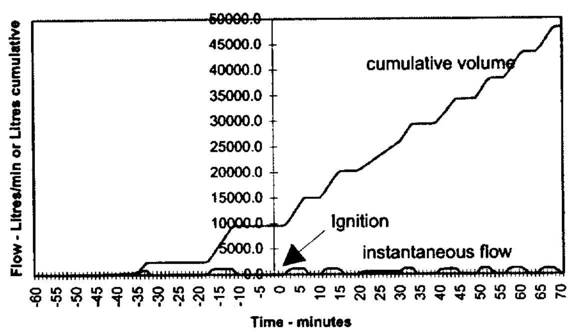
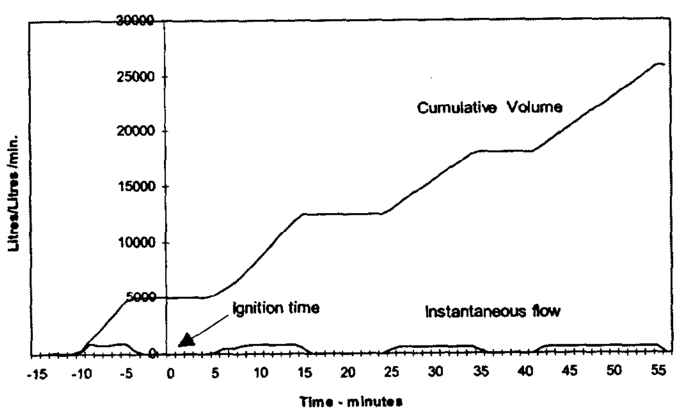


Figure 5 Pump Rate for Burn 2



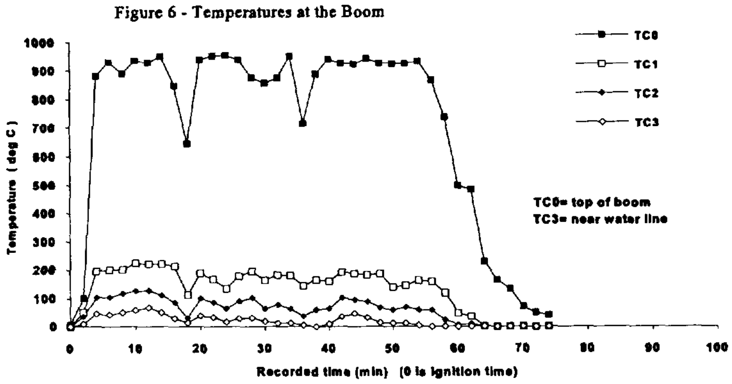
Fire-Resistant Boom Operation

The 3-M boom withstood the temperatures and strains of the burn with the exception that three flotation logs were lost from one section near, but not in the apex. This occurred near the end of the burn and did not cause leakage or any particular difficulty. Subsequent examination of the boom revealed that the stainless steel mesh holding the logs had given way. The manufacturer has modified the boom design to incorporate a heavier mesh and several other improvements as a result of this field trial.

Fire Temperature

Temperatures were recorded at several points on the fire boom. Eight sections were monitored with thermocouples at four locations in the vertical plane. Figure 6 shows a typical output. This shows that the temperatures at the top of the fire boom often reached 1000°C and the temperatures below were substantially lower. Thermocouple probes known to be in the water show no increase in water temperatures.

Figure 6 - Temperatures at the Boom



Oil Analysis

The oil was analyzed for physical properties. Table 5 shows the results. The most interesting result is that the residue appears to be an oil with an evaporative loss of about 45% by weight.

Table 5 Physical Analysis of NOBE Oil/Residue Samples

Parameter	Starting Crude Oil	Residue
Weathering Percentage	0.04	40-48%
Density	0.8437g/mL (15°C)	0.9365g/mL (15°C)
Viscosity	11 cP (15°C) (shear rate 500s^{-1}) Newtonian visc.	130500 cP (15°C) (shear rate 1s^{-1}) non-Newtonian visc.
Pour Point	-21°C	34°C
Interfacial Tension	21.4 dynes/cm (15°C) (air/oil)	Not measurable at 15°C
	13.3 dynes/cm (15°C) (oil/sea)	Not measurable at 15°C
Emulsion Formation (f_i) and Stability (f_r)	f_i = 0 (15°C) f_r = 0 (15°C)	f_i = 0 (15°C) f_r = 0 (15°C)
Asphaltene Content	0.7 wt%	2.3 wt%
Wax Content	10.1 wt%	13.8 wt%
Flash Point	-13°C	>90°C
Water Content	0.54 wt%	14.01 wt%
Sulphur Content	0.15 wt%	0.40%

References

1. Fingas, M.F., K. Li, F. Ackerman, P.R. Campagna, R.D. Turpin, S.J. Getty, M.F. Soleki, M.J. Trespalacios, J.R.P. Paré, M.C. Bissonnette and E.J. Tennyson, "Emissions From Mesoscale In-Situ Oil Fires: The Mobile 1991 and 1992 Tests", in Proceedings of The *Sixteenth Arctic and Marine Oil Spill Program Technical Seminar*, Environment Canada, Ottawa, Ontario, pp. 749-821, 1993.