UNITED KINGDOM IN-SITU BURN TRIALS, LOWESTOFT, 1996

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ABSTRACT: *On June 12, 1996, in a location 40 miles offshore of Lowestoft, an international audience gathered to watch Oil Spill Response Limited conduct the first controlled in-situ burn (ISB) in the United Kingdom. Two burns were completed using a response-prepared ISB system. The first burn involved fresh crude oil and was lit with a hand-held igniter using a standard gel mix. The second burn involved an emulsified crude and was lit using the Helitorch and an emulsion-breaking ignition mix. The trials were performed with the aim of determining operational practicalities under realistic conditions when responding to a weathered oil situation in an offshore location. Peripheral attention was paid to atmospheric sampling, except that air samples were collected aboard the main deployment vessel to assess worker safety. Oil analysis was carried out primarily to assess the values of the emulsion that was left as residue.*

In 1993 Oil Spill Response Limited (OSRL) acquired 750 feet of second-hand, 30-inch, first-generation, 3M fire boom; in so doing it included in-situ burning (ISB) in the list of OSRL response options. Ancillary purchases included a Helitorch and a new container, and in July 1994 a two-day workshop was conducted by Al Allen of Spiltec, during which the Helitorch was fired and the full length of boom was deployed. By August 1994, the ISB package and the oil spill technicians were prepared for an ISB callout. What was required next was a practical assessment of its capabilities. The aim of this project was to ascertain the practical constraints of employing ISB as an international OSRL response option.

In July 1995 OSRL set in motion a project to test the ISB strategy as realistically as possible; the oil would be released ahead of and not into the boom, the oil would be weathered according to an achievable response time arrival expectation, "vessels of opportunity" would be used to deploy the boom, and the trials would be performed according to the ambient weather conditions (upper limit permitting). OSRL wanted an end user's assessment of both the hardware and the strategy. Would emulsions burn using a Helitorch containing an emulsion-breaking ignition mix? Would hand-held igniters work? Would the boom hold up? Could a multinational team aboard "vessels of opportunity" overcome language and deployment challenges? Would worker safety be compromised? OSRL, in the role of practitioners, intended to highlight the constraints in using ISB as a response strategy.

This paper begins by stating the objectives of this study, which are followed by an operational overview. The main body of the report addresses each of the objectives in the order set out in text following. The report closes with a summary and conclusions.

Specific project objectives were the following:

1. Challenge the recognized limits of the ISB operating envelope
2. Appraise the deployment, performance, and handling of the 3M/American Marine fire boom system
3. Assess the performance of a custom-designed, hand-held igniter
4. Evaluate the practical performance of emulsion-breaking ignition technology using the Helitorch
5. Contribute to the scientific knowledge of burning oils

Operational overview

Location. The trials were conducted in the North Sea in a licensed operating box measuring 25 square miles, which lay 40 nautical miles northeast off the coast of Lowestoft, United Kingdom. The exact rendezvous position was 52°50′N, 2°55′E.

Response time. The actual response time to arrive on location, once redundant time and non-ISB equipment movements had been discounted, was 12 hours. This comprised 1 hour of trailer loading at OSRL, 6 hours of road transport to Lowestoft, 1 hour of vessel loading, and 4 hours of passage to location.

Oil type. The oil type released was Larkwhistle Farm (SG 0.8376), which is produced from an inland reservoir near the OSRL base at Southampton.

Oil volume. License was given for a total release of 60,000 liters of oil.

The fire boom. OSRL had available 750 feet of first-generation 3M fire boom (size 30 inches, measured from top to bottom), which was stored in a 30-foot ISO container that had been fitted out with a fast curtain track rail system. The boom hangs suspended in three aisles, ready for launch. American Marine Inc. donated a further 50 feet of latest-specification fire boom.

Ignition systems. One Simplex 30 US Gallon Helitorch (Model 5400) was delivered to North Denes heliport, and three Simplex hand-held igniters were stored aboard the main deployment vessel.

Backup systems. The first contingency system on standby to recover unburned oil was a heavy oil rotating drum skimmer system (WP-130), which was loaded aboard the oil release vessel. The second contingency system on standby to recover unburned oil was the fixed-wing, aerial dispersant application of Corexit 9500.

Logistic support. The air and sea logistics assembled to support the operation are shown in Table 1.

The program. The trials program started on June 11 and finished on June 12, 1996. One boom trial and two burns were completed (Table 2).

Objective 1: Challenge the recognized limits of the ISB operating envelope

These trials were performed under exacting conditions: the weather was poor, the exercise location was an unsheltered open sea environment, the operations team had to settle for vessels of opportunity, and there were language problems. This section extrapolates the information recorded during these trials, which is used to indicate the operational parameters of the ISB operating envelope. It should be noted that OSRL

Table 1. Logistics

Platform	Type
Spotter aircraft	Air Atlantique Cessna 404
Spray aircraft	Air Atlantique DC3 (Dakota)
Helitorch aircraft	Bond Sikorsky S76A
Primary vessel	French Navy supply vessel *Alcyon*
Tow end vessel	Harbor tug *Anglian Man*
Oil release vessel	Supply vessel *Eilean Dubh E*

has not drawn any conclusions from this section, because it recognizes that every oil spill is different and that what may apply in one circumstance may not apply in another.

The performance of the burns was assessed from several vantages. From the air a U.K. government patrol remote-sensing aircraft took video footage, and from a separate aircraft an invited contractor filmed the event on a military specification thermal imaging camera. At sea level, remote photographic evidence was taken from all the platforms. The observers who worked closest to the boom apex consisted of representatives from OSRL, CEDRE, American Marine, and Spiltec; they operated from an inflatable belonging to the *Alcyon*. During burn periods the inflatable was stationed astern of the towing vessels so that observers could witness the burn from as close a point as possible. The consensus opinion of this team has been used to analyze the performance of the burns.

A burn rate figure of 0.07 U.S. gallons/minute/foot^2 (2.85 liters/minute/meter^2), which has been used on several controlled burns with fresh oil, was used to calculate the amount of oil burned within a nominal oil containment area adjudged to be one-fourth (116 to 162 m^2) of the nominal burn area.

Burn 1. Burn 1 involved the release of 15,000 liters of fresh oil close to the opening of the boom. The "intense burn" lasted 13 minutes. A "reduced burn" then continued for 6 minutes; the average area of the burn was approximately half that of the intense burn. The flame heights appeared to be about 50 to 80 feet (15 to 25 m) during the intense part of the burn.

Upon completion of the burn, approximately 160 liters of residue remained; 80 liters was floating in a patch 2 m^2 in area and 4 cm thick, with a similar quantity coating the boom. The fraction of residue remaining constituted 2% to 3% of the amount burned; the amount burned was in the order of 36% to 50% of the amount released. The total amount of oil burned was reckoned to be between 5300 and 7400 liters.

Weather conditions at the time were as follows: sea state 4/5, wind speed 20/25 knots, current rate 1.8 knots. The vessels headed with the current, with the wind at a relative direction of green (starboard) 120°.

Burn 2. Burn 2 involved the release of 18,000 liters of emulsified oil that had been evaporated by 14% and emulsified with a 25%-by-volume water content. The "intense burn" lasted 18 minutes. A "reduced burn" then continued for 8 minutes; the average area of the reduced burn was approximately half that of the intense burn.

After the burn was completed, approximately 320 liters of thick taffy-like residue remained. The fraction of residue remaining constituted 3% to 4% of the amount burned. The amount burned was in the order of 54% to 75% of the amount released. The total amount of oil burned was estimated to be between 7280 and 10,160 liters.

Weather conditions at the time were as follows: sea state 4, wind speed 20 knots, current rate 1.8 knots. The vessels headed with the current, with the wind at a relative direction of green (starboard) 120°.

Table 2. ISB trials program

Date	Trial	Objective
6/11/96	Boom	Released 160 liters of green fluorescein dye to act as a realistic marker, which the vessels crews could use to rehearse boom-handling skills.
6/12/96	Burn 1	Released 15,000 liters of fresh crude oil for containment, and applied a hand-held ignition system filled with a standard gel mix.
6/12/96	Burn 2	Released 18,000 liters of crude oil emulsion, weathered to a response time expectation of 12 hours, and applied the Helitorch filled with an emulsion-breaking ignition mix.

Objective 2: Appraise the deployment, performance, and handling of the 3M/American Marine fire boom

Deployment of the fire boom. The curtain track design of the OSRL fire boom container ensured an easy deployment. The only interruption required in an otherwise smooth launch of the 750 feet of 3M fire boom was to insert one 50-foot section of the latest American Marine fire boom into the apex position.

The nominal length recommended for a fire boom is 500 feet. OSRL chose to use 750 feet, fearing that 500 feet would be too short. The reason for choosing 750 feet was not that the containment area would be too small, but that OSRL felt that a longer boom would compensate for any handling deficiencies or mistakes on the part of the vessels. In hindsight it should have been even longer, perhaps as long as 1000 feet. (Not all the boom needs to be fire boom; fire boom can be supplemented with "leader" boom. As long as the burn can be restricted to the fire boom portion, there will be no reduction in operational performance. Clean Caribbean Co-operative [CCC] has a fire boom system that is configured with "leader" boom.)

The size of both the 3M and American fire boom was 30 inches, as measured from the top of the buoyancy chamber to the bottom of the skirt. The diameter of the buoyancy chamber, which can vary from model to model, was 18 inches.

Performance of the fire boom. After burn 1, all 550 feet of fire boom remained intact. The polyurethane outer sheathing of the sections nearest to the apex of the boom had been destroyed, but the fire-retentive design of the boom was not impaired. After burn 2, the condition was similar to burn 1, but with more sections of the boom having sacrificed their polyurethane outer cover.

Because of kinking of the tensile load member, the boom broke on the first day of the trials, just as 160 liters of fluorescein was entering the boom as part of the boom trials. The tensile load on the boom is taken up by a chain tension member that runs along the skirt; this fastens to the connectors with a quick link, and herein lies a problem. When you deploy the boom, you have to make sure that the chain is kink-free. If, as happened on the first day of trials, the chain develops a kink, the tension locks the kink in that position, excess force is brought to bear at that point, the link distorts, and eventually it breaks.

The boom parted at one-third distance, leaving 550 feet with the primary vessel and 200 feet with the towing vessel. One of the "quick links" that had been used in 1988 to attach the boom end connectors to the boom chain had caught at an oblique angle to the connector, allowing the tension load in the ballast chain to strip the threads of the "quick link" and force it open. When this happened the main tension load member of the boom was open, allowing the tension applied by the tow vessels to strip the fabric, wire mesh, and Nextel fireproof fabric from the connector and open the boom. It should be noted that the use of these "quick links" was discontinued in all American Fire boom from 1989 on in favor of stainless steel shackles. However, it would be wrong to discount (1) the role played by the vessels, whose station keeping was wayward, and (2) the action of the weather. At the time the boom parted, the aperture gap was 0.5 to 0.6, and the weather was at the limit of oil containment performance. Either of these could have contributed to the failure.

The damage that occurred was investigated firsthand by the president of American Marine, Inc. The problem had not been encountered before, and a solution is required. In the immediate term, the solution was to remove the damaged section and ensure a kink-free redeployment.

Handling of the boom. Hand grips affected the handling of the boom. It is my opinion that the sheathed wire cord straps atop the American Marine fire boom were better than the web straps atop the 3M boom. The degree of water retention of the booms also affected handling. Upon recovery it was noticeable that the American Marine fire boom retained less water than the 3M fire boom, which made it easier to handle.

OSRL does not want to attach too much significance to the method of recovering fire boom, since once used, the boom has served its purpose. However, there are two reasons for considering an efficient recovery system: (1) a recovery may need to be expedited if the boom system needs to be repositioned for an oil deposit remote from the current location; and (2) assuming that the fire boom has served its purpose and can be recovered, there is a good chance that some fire boom sections not exposed to the burn can be used again. In the case of these trials, 250 feet was salvaged for further use. The system devised by OSRL for recovering the fire boom consisted of a hydraulically powered deck reel. The deck reel method failed because the boom was too rigid to wind around the bobbin. The only option left was a laborious process of stopper and pull, stopper and pull, similar to that used on day 1, using the deck reel as a winch instead of a winder. Alternative recovery methods had been investigated, most notably involving the use of a crane with a mechanical grab bucket to claw in the boom, but this suggestion was rejected on the grounds that using a heavy crane in anything but calm seas would compromise worker safety. The idea of using a floating pickup tray had also been considered, but, like the grab bucket method, it relied on a high seas crane to lift the tray out the water.

Objective 3: Assess the performance of a custom-designed hand-held igniter

Simplex provided four hand-held igniters that were all of the same design to be tested as incendiary devices as part of an ISB system. OSRL intended to use them as a first option for burn 1 and as a contingency option for burn 2.

The design of the igniter used raw materials that consisted of polystyrene side floats, a plastic jar axis, and a standard 6-inch marine hand-held distress flare that was directed toward the jar so that the flame burned through the plastic and ignited the gelled oil contents. The hand-held igniters used in these trials are shown in Figure 1.

The gel used was a standard mix and consisted of 1 liter of gasoline mixed with 0.01 kg of “Sure Fire Fuel Thickener” (aluminum soap). The igniter was cast into the boom opening from an inflatable boat positioned upwind of the boom. The results were that the igniter drifted directly into the apex, with the flare burning for 60 seconds. The flame penetrated the plastic jar and lit the gel. The oil caught fire shortly afterwards.

Objective 4: Evaluate the practical performance of emulsion-breaking ignition technology using the Helitorch

One of the key success factors central to the trials was the formulation of the emulsion-breaking ignition (EBI) mix. EBI ground studies had been performed by SINTEF, and the results looked promising.

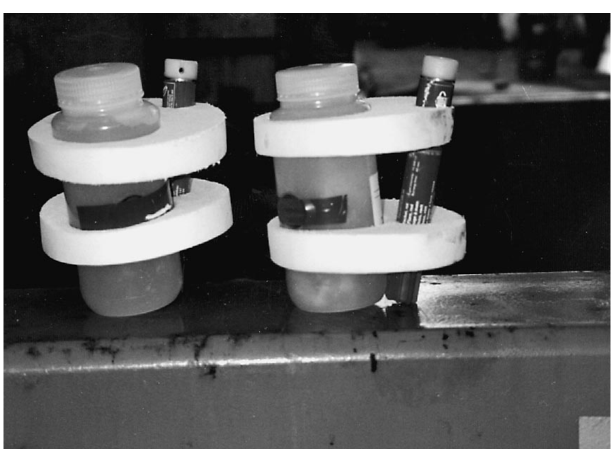

Figure 1. Hand-held igniters

Table 3. Emulsion-breaking ignition formulation

Item no.	Ingredients	Ratios (approximate)
1	Intermediate Fuel 30 (IF 30); comprises 39% Gasoil and 61% IF 380	39%
2	Gasoline	57%
3	Alcopol 60	4%
4	Sure Fire	12%–15% by weight of Items 1 + 2 + 3

OSRL elected to adopt this innovative approach to burning emulsions and sent all the necessary ingredients to SINTEF for laboratory testing. This section deals with the efforts made to translate laboratory work to the field using the Helitorch as the applicator.

The emulsion-breaking ignition (EBI) recipe was based on laboratory experiments that had shown that, by combining Bunker C with Intermediate Fuel 30 and demulsifier and gelling it with Surefire powder, one could produce an EBI gel that would ignite stable water-in-oil emulsions. The result of the laboratory trials was to recommend the formulation shown in Table 3.

The most significant aspect of this recipe is the dramatic increase in gelling powder required to bind this formulation, as compared with a standard formulation; this increase is due to the addition of the demulsifier. Based on the requirements for the 30 US gallon model Helitorch, the difference is 1.135 kg for a gasoline gel as compared with 12 to 15 kg for this EBI gel. This extra dosing requires very careful mixing to avoid a lumpy gel. The EBI recipe was deployed using the Helitorch.

Some preparations had to be implemented prior to this trial. The Helitorch OSRL purchased a Simplex Helitorch, Model 5400, 30 US gallon capacity, that had FAA-type approval, but this did not accredit it for use in the United Kingdom. Before the unit could be used on these trials, OSRL had to earn Civil Aviation Authority (CAA) approval. The air worthiness license to carry and deploy the system, underslung by a Bond Sikorsky S76A, was only granted after a flight test, a Helitorch firing test, and a subsequent modification program had been performed and inspected. The license took 6 months to obtain and is restricted to the specific unit tested and to the use of Bond Helicopters Limited as the carrier. Other carriers could apply to operate the system, but they would need to apply to the CAA for a supplement to their Rotorcraft Flight Manual detailing the installation inspection routine. The modifications carried out by OSRL to address the deficiencies identified by the CAA are shown in Table 4.

When the Helitorch was being filled with the EBI mix, there was a significant increase in gelling powder required by the EBI mix over the standard mix, which meant that great care had to be taken in adding the powder. Unfortunately, mistakes were made. These included not using fresh powder (it was 2 years old), not sieving the powder, not making up the mix in a batch method (it was made all at once), rushing the mix (a communication problem), and not testing the EBI mix in the Helitorch prior to use. The upshot of all of these factors was a gel of uneven consistency.

The results of applying the EBI mix with the Helitorch follow. It was deployed under a Bond S76A helicopter. A stand-alone 28-volt DC feed battery was fitted in the aircraft and was used to power the electrical actions. When airborne the Helitorch hung in line with the aircraft, with the nozzle facing to the rear. Initially the aircraft flew a dummy circuit so the observers in other aircraft and vessels could see the equipment and the air crew could observe the arrangement of vessels and boom. The helicopter then flew by the vessels at 35 knots/170 feet for a full test run. It was apparent that the ignited gel fuel was extinguished prior to hitting the sea surface. A further test run was flown at 120 feet and 25 to 30 knots. Ignited oil did reach the sea surface but extinguished immediately. At 60 to 70 feet and 20 to 25 knots burning gelled oil reached the surface. Four attempts were made to ignite the emulsified crude oil contained within the fire boom. The fourth attempt was successful (Figure 2).

Table 4. Helitorch modifications ordered by CAA

Modification no.	Description
1	Drum vent flame retarder (already incorporated by OSRL at initial inspection)
2	Drum retention straps: two 500-kg ratchet tensioned cargo straps to secure the drum to the frame
3	Lower strop attachment fittings: articulated linkages to alleviate cable kinking
4	Propane cylinder securing brackets: fail-safe clamping arrangement
5	HT lead rerouting and clipping: separation from propane and petroleum gel pipes and p-clipping to base

Although the burn started after the fourth pass, the consensus opinion of most observers was that the fire had in fact started on pass 3, when an orange burst was seen to emanate from the oil, only to be quelled by the down-wash from the propeller blades. My belief was that a smoldering fire had started after pass number 3 that just needed time to take hold, only manifesting itself once the aircraft had made its fourth and final pass.

When the Helitorch returned to North Denes and the rehabilitation commenced, it was revealed that the EBI mixture had clogged the feed pipe to the nozzle. A semisolid plug of gelled fuel was later removed at the OSRL workshops.

Objective 5: Contribute to the scientific knowledge of burning oils

OSRL set out to establish the practical issues related to ISB; collecting scientific data was incidental. However, there were two elements to the program that would require scientific support: (1) Would occupational exposure limits to airborne contaminants be exceeded? (2) How much water was contained in the emulsion before release? A third element that was not considered critical because of the pragmatic nature of trials but was nevertheless included was laboratory analysis of the oil samples taken before and after each burn. The results of these three scientific elements are discussed in text following.

Air monitoring. The air-monitoring program designed to assess worker exposure to burn emissions was carried out aboard the main deployment vessel *Alcyon* by a company called Casella of the United Kingdom. The scope of work involved measuring concentrations of particulate matter, combustion and acid gases, organic compounds, and metals against occupational exposure standards. The sampling was performed from the working deck, bridge deck (port and starboard wings), and forecastle of the primary deployment vessel *Alcyon*. Open deck personnel were required to wear particulate and organic vapor masks during each burn episode as a precautionary measure. The following caveats are important when evaluating the data obtained during this aspect of the project:

1. At no stage were samples taken directly from in or under the plume. The closest point of a sample was 30 meters from the center line of the plume.
2. The concentration of airborne pollutants in and under the plume was not established in this study; therefore, the impact of exposure to the plume and its effect on air quality cannot be assessed and may warrant further investigation.
3. It should be noted that the burns undertaken were small and were performed during relatively calm and stable weather. The extrapolation of data obtained from this study to larger burns under different weather conditions may not be realistic.
4. Open deck personnel were required to wear particulate and organic vapor masks during each burn episode as a precautionary measure.

Comparison of the data recorded before and during each of the burns (Table 5) shows slightly elevated concentrations of airborne nitrogen oxide, sulfur dioxide, particulate matter, and chloride as compared with background levels, but at concentrations insignificant in occupational exposure terms.

One compound not shown in Table 5 that was detected downwind on the first burn above the method detection limit of 0.1 mg/m^3 was dibutyl phthalate. This is a common plasticizer (probably originating from the fire boom) and is not considered to be a genuine contaminant.

The conclusions offered by Casella were as follows:

1. The data obtained from the air monitoring performed indicate that, 30 m beyond the center line of the plume, the burning of oil at sea has no significant impact on the quality of air, as shown in Table 5, but the caveats described in text preceding should be taken into account.

Figure 2. Emulsion burn

Table 5. Results of air monitoring undertaken during the burn trials

		Concentration detected (mg/m^3)				
Parameter	Preburn	Bow deck 1st burn	Bridge (P) 2nd burn	Bridge (S) 2nd burn	Working deck 2nd burn	Occupational exposure limits (OEL)
Nitric oxide	0.300	0.320	0.900	0.710	0.740	OES = 30[2]
Nitrogen dioxide	0.230	0.350	0.800	0.630	0.600	OES = 5[2]
Particulates	<0.010	<0.010	0.280	<0.020	0.110	OES = 10[2]
Sulfur dioxide	0.060	0.070	<0.120	0.540	0.180	OES = 5[2]
Hydrogen chloride	0.270	0.310	0.930	1.370	0.680	OES = 7[3]
Hydrogen fluoride	<0.010	<0.010	<0.020	<0.020	<0.020	OES = 2.5[3]
Vanadium	<0.020	<0.020	<0.040	<0.040	<0.040	
Nickel	<0.002	<0.002	<0.004	0.008	<0.004	MEL = 0.5[2]
Chromium	<0.002	0.004	<0.004	0.008	0.008	OES = 0.5[2]
Organics	<0.100	<0.100	<0.100	<0.100	5.700[1]	

1. Organics detected comprised *n*-alkanes and cyclic hydrocarbons.
2. 8-hour time-weighted average.
3. Short-term exposure limit.

2. It would appear that the health hazards associated with exposure to airborne pollutants arising from the in-situ combustion of oil are negligible, providing that exposure to pollutants in or under the main plume does not occur.

Emulsion analysis. The oil samples were collected from an inflatable boat using a water trap column tube. A remote wire pull cord for opening and closing the trap was available, but the manual plunging method sufficed. The samples were dispatched to M-Scan (subsamples were sent to Inchcape Testing Services for water content analysis by Dean & Stark using IP Method #74). The results of the analysis were not consistent with expectations. The sample taken from the prepared emulsion for burn 2 indicated that the water content was 1% by volume. Derivation of the water content by sounding methods had revealed 25% by volume. The reason for the spurious results is most likely the presence of demulsifier in the crude oil. The oil producers had injected the crude with demulsifier at 100 ppm as part of a standard operating procedure designed to prevent emulsions from forming. An aerial photograph clearly showed that an emulsion was formed of the order indicated by the findings.

Oil analysis. M-Scan carried out the gas chromatography and mass spectrometry analysis of the samples collected (Table 6).

The conclusions offered by M-Scan are as follows:

1. The burning of the oil samples has significant effects upon the distribution of components. The main effect is loss of volatile compounds, resulting in an increase in viscosity.
2. The total concentration of polyaromatic hydrocarbons (PAHs) within the samples is reduced as a consequence of combustion and evaporation. There is a shift in the distribution of PAHs after burning, favoring unsubstituted parent compounds and higher-molecular-weight species. However, the proportion of alkylated PAHs still present in the burnt oil samples indicates that combustion took place at relatively low temperatures.

Table 6. Oil samples sent for analysis

Sample no.	Source	Date	Notes
1	Fresh oil tank	06/11/96	Fresh “Larkwhistle Farm” crude
2	Emulsion oil tank	06/11/96	Emulsion
3	Boom apex	06/12/96	Preburn 1 from tank 1
4	Boom apex	06/12/96	Burn 1: residue
5	Boom apex	06/12/96	Burn 1: residue
6	Emulsion oil tank	06/12/96	Preburn 2
7	Boom apex	06/12/96	Burn 2: residue
8	Boom apex	06/12/96	Burn 2: residue

Summary and conclusions

These trials were not designed as a scientific experiment because OSRL knew that fresh oil burned and had no desire to validate any previous research, other than to advance scientific findings. What OSRL wanted to learn were the practical, operational considerations attached to implementing an ISB strategy. OSRL put this aim to the test with a response-prepared fire boom system that was deployed in an offshore location using “vessels of opportunity.” Weathered oil was released. Along with some unpredictable weather, all the elements were present that modeled a real event.

The results were encouraging; oil aged by 12 hours with a 25% water content burned down to a 3% to 4% residue, the fire boom survived two burns intact, the hand-held ignition systems worked, and the Helitorch lit emulsified oil using EBI. The trials were not without their problems, and adjustments had to be made, but the trials met the aims and objectives asked of them.

The conclusions arising from the trials are as follows:

1. The launch system of hanging the fire boom in a container using castor wheels that slide onto a rail track system was a success.
2. The improvised recovery method using a hydraulically driven deck reel was not a success.
3. The nominally recommended fire boom length of 500 feet is too short.
4. The chain link design of the tension member on the 3M and the American Marine fire boom is prone to “lock kinking,” which disrupts the linear travel of the tensile load and leaves the boom susceptible to a partial or full-stress tear.
5. Emulsified oil can be ignited and will burn.
6. The EBI mix requires too much gelling powder (13 times more than normal) to compensate for the merit of adding demulsifier.
7. Oil will continue to burn with wind speeds of up to 30 knots.
8. The data obtained from the air monitoring performed indicates that, 30 m beyond the center line of the plume, the burning of oil at sea has no significant impact on the quality of air (see Table 5), if certain caveats are taken into account.
9. It would appear that the health hazards associated with exposure to airborne pollutants arising from the in-situ combustion of oil are negligible, providing that exposure to pollutants in or under the main plume does not occur.

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Biography

James Thornborough joined Oil Spill Response Limited in 1988 as a technician after 5 years of service as a deck officer with the Royal Fleet Auxiliary. He has been a training officer and response team leader and is currently a senior planning consultant. He has had the following experience with oil spills: *Exxon Valdez*, United States; *Khark V*, Morocco; *Rose Bay*, United Kingdom; *Mega Borg*, United States; *Nassia*, Turkey; and *Sea Empress*, United Kingdom.