Burning Issues

By JANET RALOFF

Is torching the most benign way to clear oil spilled at sea?

Seven weeks ago, more than 200 researchers from around the world observed a rare and dazzling bonfire. What distinguished the spectacle was not the dense, roiling soot plumes, some of which eventually climbed 4,000 feet into the air, nor the flames, which rose 300 feet and more during much of the nearly three-hour-long performance. Rather it was the venue: the North Atlantic's Grand Banks, 25 nautical miles east of Newfoundland.

The participants arrived at the staging area in a flotilla of 12 boats that left St. John's Harbor around 3:30 a.m. Ringside seats were anything but cushy — the cockpit of one of three circling helicopters and the open bench seats in one of five 21-foot work boats. Those willing to watch from a little farther away had more stable viewing platforms — anything from fishing trawlers to the Canadian Coast Guard's *Ann Harvey*, a six-year-old, 272-foot-long icebreaker. Even on the bigger vessels, however, people popped motion-sickness pills liberally.

Despite the discomforts, few present for the blaze voiced complaints. Indeed, for many, this — the Newfoundland Offshore Burn Experiment (NOBE) — was a dream come true. Execution of the complicated field trial, four years in the planning, occurred almost without a hitch. More important, the $6.5 million research mission provided an unparalleled opportunity to glean insights into the behavior — and prospects — of fire as an oil-spill cleanup technique.

The idea of burning slicks at sea has intrigued oil-cleanup managers for more than a decade. But it wasn't until the advent of fireproof booms in the mid-1980s and a major "spill of opportunity" — the March 1989 *Exxon Valdez* accident — that *in situ* (on-site) burning got a real sea trial.

Early on the second evening following the *Valdez* spill, two hired fishing boats began towing a 450-foot boom through scattered slicks of oil. Within about 30 minutes, the now U-shaped fire boom had collected between 15,000 and 30,000 gallons of Alaskan North Slope crude from calm seas, according to Alan A. Allen of Spiltec in Woodinville, Wash., who coordinated the exercise.

Once the boats towed the oil clear of other slicks, Allen ignited a small plastic bag of jellied gasoline and allowed it to float into the boomed oil. In 15 minutes, the corralled crude was burning intensely, sending up flames more than 200 feet. When the fire died out, Allen recalls, 95 to 98 percent of the oil was gone. All that remained were some 300 gallons of sticky, but buoyant, clumps of taffy-colored residue. "And they proved very easy to pick up," he says. "Nets would have been ideal."

Authorization came through to burn another batch of *Valdez* oil the next day. But by morning, Allen says, stormy seas, the inevitable emulsification of the floating oil and water, and the crude's weathering (rapid loss of its most combustible components) had rendered that decision moot. The window of opportunity for burning had slammed shut.

However, the ease, low cost, and lack of experience needed for two small boats to eliminate so much oil in a mere 45-minute blaze did not escape the attention of federal agencies charged with responding to offshore spills. Indeed, it only intensified their burn-research efforts, notes NOBE coordinator Merv Fingas, director of the Emergencies Science Division of the Canadian government's Environmental Technology Center in Ottawa.

Even "nonparticipants" — such as Canadian government observers Jerry Payne and Kathy C. Penny — pitched in to help during NOBE. Here, they close cannisters that sampled sidestream levels of organic chemicals during the fires.

Fires will never offer the answer for every spill. Effectively containing the oil for ignition and protecting valuable resources nearby (such as a tanker or offshore-oil platform), for instance, requires the use of booms. Flexible, fabric fences that straddle the water's surface – rising about 1 foot or so above and extending roughly 3 feet below – the booms now in use begin losing their ability to contain oil when winds exceed 15 to 20 knots and short, choppy waves exceed 2 to 3 feet.

Many oils also emulsify – entrain water – quite readily. The ability to ignite oil becomes increasingly difficult with emulsification, and virtually impossible once the water content of a slick hits about 60 percent.

Fires might also prove risky in areas close to major population centers – such as San Francisco Bay – or where burning might endanger wildlife.

However, where conditions allow it, nothing can compete with fire's ability to remove oil from water, studies indicate. Burns have the potential to remove as much oil in one day as mechanical devices – booms, skimmers and sorbents (SN: 5/22/93, p.332) – can in one month, Fingas notes.

Moreover, he adds, removing spilled oil by burning requires "minimal equipment and much less labor than any other technique." Mechanical cleanup tools generate immense quantities of wastes that require disposal – often equaling two to five times the volume of oil spilled. By contrast, in tests, burning commonly eliminates 90 to 98 percent of the pollution on the spot.

The result? Allen estimates the likely cost of *in situ* burning may run just $20 to $50 per barrel of oil eliminated. That's well below the $100 to $150 per barrel recovery cost associated with mechanically skimming spilled oil from water and the $10,000 or more per barrel that Exxon sometimes spent to clean certain heavily oiled and highly valued beaches in Alaska after the *Exxon Valdez* spill.

Notwithstanding these advantages, Fingas observes that burning "has never been fully accepted as an oil-cleanup option." In fact, despite its successful test after the *Valdez* accident, no one has intentionally employed controlled burning in any sea spill since.

The principle reason, Allen and Fingas argue, is public reluctance to sanction fire's copious generation of oily, black smoke (see sidebar, p.223).

The U.S. and Canadian governments are addressing that concern by focusing their cooperative research program of *in situ* burning on environmental studies – largely soot generation, water-quality issues, and analyses of toxic combustion gases. NOBE was the first attempt to test how well more than a decade of small- and medium-scale oil fires model what would occur in a full-scale burn at sea.

The unexpected: A fire boom fails

To continuously feed two test fires, NOBE scientists had planned to slowly pump slightly more than 26,000 gallons of Alberta sweet crude oil into the North Atlantic. A 700-foot-long fire boom was deployed for the dual task of preventing the spilled oil from breaking free and controlling the slick's dimensions – and area aflame.

The first 90-minute blaze went according to plan. But a little more than midway through the second burn, the fire boom – a flexible, segmented fence of ceramic and stainless steel – began falling apart. NOBE scientists, who diagnosed the problem before any oil could escape, immediately cut off the flow of fresh crude.

Halting this second burn in no way compromised NOBE, Fingas said at a scientific briefing the next day. Because each burn ran about 50 percent longer than planned, project scientists had already collected more data on air and water quality than they had expected.

Nonetheless, the deterioration of the boom – previously considered one of the most reliable facets of *in situ* burning technology – surprised everyone.

"We won't know exactly what happened until we see samples of the boom. They are being sent back to our laboratory right now," says Bob Cuerden of 3M Company's Ceramic Materials Department in St. Paul, Minn., the boom's maker.

Many researchers who participated in the Newfoundland burns were less circumspect. "It [NOBE] confirmed for me the need to advance the science of fire boom development," says Alan A. Allen, an oil-spill consultant. A version of this boom "looked good after 48 hours of continuous burning in all of our static tests," he said on the morning after the burn. But the surface of the North Atlantic isn't static. Even on the unusually calm day chosen for the NOBE trials, waves flexed the boom every three seconds or so.

Indeed, the boom's failure highlights a need to test this equipment under the *dual* stress of fire and waves, argues Robert Hiltabrand, with the Coast Guard R&D Center in Groton, Conn. However, he adds, no facility currently exists to do so. And U.S. researchers have been unable to get federal approval to conduct *in situ* burning experiments in open U.S. waters.

While the Coast Guard has begun allowing manufacturers to test prototype booms during fires at its Sand Island facility, its tank lacks wave action. But Hiltabrand hopes within two years to have a new, 50-by-250-foot tank on Sand Island that can simulate ocean wave action during oil-burn tests.

Edward J. Tennyson of the Minerals Management Service (MMS) hopes to have the same capability even sooner. MMS currently operates a large, open-air test tank in Edison, N.J. Some 670 feet long and 66 feet wide, it can simulate complex combinations of waves and tow speeds to 6 knots. Before the facility was mothballed in 1987, experimental burns also took place there. But prior to the tank's reopening last year, New Jersey instituted a ban on open-air burning.

NOBE

Photo shows missing float – one of the buoyant cylinders that anchors the boom's oil-containing skirt at water surface. This boom lost two floats from an experimentally redesigned segment.

Tennyson now hopes to get a waiver. On Sept. 2, he began the process of applying for a state permit to again conduct test burns in the New Jersey tank.

Meanwhile, can the current generation of fire booms be trusted? Even after NOBE, Allen, Fingas, and Tennyson believe it can. While each said he would like to see booms perform reliably for longer than three hours, Allen notes that most spills will probably not involve individual burns lasting even two hours. And between burns, Allen points out, a boom can be inspected and any failing segment removed or replaced.

– J.A. Raloff

Most of those smaller studies, in recent years, have been conducted at the National Institute of Standards and Technology (NIST) in Gaithersburg, Md., and at the Coast Guard Fire Safety and Test Detachment on Sand Island in Mobile Bay, Ala.

NIST's program has focused on the mechanics of combustion and its generation of sooty smoke. Such studies indicate that oil tends to burn at a fairly predictable rate. In general, fire will consume about one barrel per minute for every 50 square meters of burning surface, according to David D. Evans, who heads NIST's Large Fire Research Group.

Such findings also mean "you are incapable, physically, of burning the oil down to the water surface," Evans notes. Generally, when an oil fire goes out, 1 mm of residue remains. But especially where towing is used to control the size of a burn – by concentrating the oil back into the apex of the boom – "that 1 mm zone is going to be small," Evans adds.

At an oil-spill conference in Tampa earlier this year, Evans also reported on temperature data from a series of Sand Island tests. Even after a vigorous 18-minute burn – where surface temperatures hovered around 575°F and ultimately caused some of the water to boil – heat from the blaze penetrated below the surface only to a depth of about 3 centimeters.

Downwind of the fires, the smoke separated into two or three counterclockwise-rotating plumes. Each eventually took its own path – some eventually traveling in directions 180° from each other, and at widely different altitudes.

NOBE

Smoke production can vary dramatically, and tends to depend on the size of the blaze. Smoke equals 6 percent of the spilled oil's weight for fires less than 2 square meters in area, to about 13 percent of the mass of the oil for burns 50 square meters and larger. Smoke output also varies with oil type. For example, in small tests in the laboratory, Murban crude (produced in the United Arab Emirates) burns with 20 percent less smoke than Louisiana crude.

The difficulty measuring smoke's outdoor dispersion has led NIST analysts to simulate the problem mathematically. Their complicated computer model has been used to plot the likely trajectory of smoke from Sand Island fires, including where it may touch down, depositing soot and other pollutants. Smoke sampled from aircraft up to 6 miles downwind of the NOBE fires now will be used to help refine that model, Evans says, as will sea surface measurements collected about 2 miles downwind of some pool fires at Sand Island later this month.

Pre-NOBE studies also suggest that fires will not propagate from one area to another across thin sheens of oil. To ignite, a slick must be at least 2 to 3 millimeters (mm) thick. Indeed, this limitation tends to dictate the need for booms around spills in open waters. Without them, oil can quickly spread out into thin layers that lose too much heat to the water to sustain a flame.

The Environmental Protection Agency and Environment Canada, with funding from the U.S. Minerals Management Service (MMS), are jointly studying potentially toxic gases emitted by burning oil. Their laboratory and tank tests indicate that burning will not increase the levels of polluting aldehydes, ketones, dioxins, furans, and polycyclic aromatic hydrocarbons (PAHs) above those that normally evaporate from spilled oil.

Overall, says Edward J. Tennyson of MMS in Herndon, Va., these data indicate that, in a burn, lighter weight PAHs tend to get converted to heavier ones. Ordinarily that's not a positive trend, he adds, since the heavier-molecular-weight compounds generally are considered more toxic. However, burning significantly reduces the overall concentration of all volatiles associated with a slick – "by somewhere between 5 and 75 percent," depending on how quickly it occurs – and therefore lowers the toxicity of air around the spilled oil. Tennyson is MMS' oil-spill-response program manager.

At NOBE, as they will again in Sand Island tests later this month, scientists mapped the generation and spread of more than 1,000 discrete chemicals from burning oil. Earlier studies have indicated that these invisible combustion gases do not travel with the smoke plume, but instead go in all directions – even upwind to some extent.

Ironically, Tennyson says, analyzing these gases has become a problem not so much of quantifying their presence but of interpreting the significance of recorded concentrations. "When we started this work in 1983, we said [to policymakers], if you can tell us what compounds you're interested in and at what level they will cause you concern, we can establish a means to measure them." Aside from some general comments about volatile organics and soot, he's still looking for guidance about which pollutants to study and at what air concentrations they may constitute a likely hazard.

Without such direction, Tennyson says, this massive international program will never successfully answer the ultimate question: How close to population centers and valuable resources can a burn be conducted safely?

Early next year, he intends to repeat his request for guidance at a workshop for those charged with setting oil-spill-response policies. "We're going to start out saying, 'Here's what we've learned from laboratory work, [tank] tests, and preliminary analyses of NOBE.' Then we'll ask: 'What do you need us to look at?' It's really their call."

The relatively small pool fires used to glean data on burning prior to NOBE suffer from a number of limitations. Effects seen in small fires don't always parallel what happens in large conflagrations. Even the 50-by-50-foot tanks used at Mobile Bay's Sand Island don't have waves, which can affect how effectively booms contain oil – before or during a burn (see sidebar, p.221). And researchers can test certain operational issues today only on open waters – questions such as how quickly and effectively booms can be deployed and towed, and whether crews can manage burns safely.

NOBE was designed to study such factors – and confirm environmental effects measured in smaller, tank fires. And as a research venture, says Fingas, "almost every portion of [NOBE] was a complete and unmitigated success."

Though final analyses won't become available until early next year, preliminary data appear to confirm many features seen in smaller fires. For instance, at least 99 percent of the spilled oil burned off the surface. And though the fires generated angry, black clouds above the oil, most of the smoke dispersed quickly – with little apparent fallout beyond a half mile. Game officials and biologists who patrolled the area from boats and helicopters throughout the entire exercise also found no evidence of curious animals that were drawn to investigate the oily inferno.

The NOBE burn also turned up a few puzzles and new phenomena. For instance, though some oil washed over the boom as each fire was due to get underway, even that burned without leaving behind the characteristic 1-mm-thick sheen of oil. Instead, it stuck to the boom and burned down to almost nothing. Why this happened "remains very puzzling," Fingas says.

A number of researchers riding the waves near the fires also expressed bewilderment at how quietly the fire burned. Absent were the roar and explosive popping characteristic of tank fires. Moreover, Fingas says, peak temperatures appear to have reached about 2,000°F, yet failed to induce the water-boiling typically seen in those smaller fires.

Among other unexpected findings, oil appeared to wick up the inside of the boom, creating a sustained flame above its buoyant collar.

Finally, researchers at previous test burns had been unable to follow the oil's smoke beyond about the half-mile mark, where it appears to fade away. At NOBE, an airplane watched the plumes travel several miles. And these new observations show the smoke did not rise as a single stream of pollution, but instead divided into two or three discrete swirling entities that traveled different paths. This was not visible from the ships, Fingas notes.

Despite the wealth of data gleaned during NOBE, no one expects experimental burns at sea to become the norm. They're simply too expensive, Fingas observes, and planning them is a logistical nightmare.

Moreover, Tennyson jokes, "We would quickly become the world's leading polluter – under the guise of environmental protection – if we tried to answer every question in the field."

But perhaps the biggest reason is a reluctance by the federal government to sanction such tests in U.S. waters. For almost two years, the international *in situ*-burning research community has been petitioning the Environmental Protection Agency to conduct two such sea trials. "And EPA has not been willing to issue a permit to intentionally discharge oil for research purposes," says Commander Kenneth W. Keane of the Coast Guard's marine environmental protection division in Washington, D.C.

After NOBE, are such additional full-scale trials even necessary? Though Tennyson would like to see at least one more – in warm waters, probably about two years from now – he concedes such a test probably would fail to turn up anything new.

For now, Keane says, "We hope that [NOBE] will provide us with sufficient scientific data that we can move forward with preplanning and preapproval for *in situ* burning where appropriate." To date, only Alaska has developed such a preauthorization for the use of burning – and even then, the preapproval applies only to spills in certain regions and under well characterized conditions.

Most public reservations about the technology come down to concern over the smoke and gases it will emit. "But in my view, 45 minutes of air pollution is much better than a couple of years of beach inundation by oil," Keane argues. "It boils down to common sense."

In fact, he told SCIENCE NEWS, "I've already put out policy that says [burning is] a viable response tool. Consider it for your area." He was referring to a July 26 package of information that he provided each of the Coast Guard's on-scene coordinators – the only individuals who can decide to burn oil in U.S. coastal waters. A formal policy statement included in the package asked the Coast Guard's regional offices to "encourage" state and federal organizations involved in setting spill-response policy "to plan for and preapprove the use of *in situ* burning."

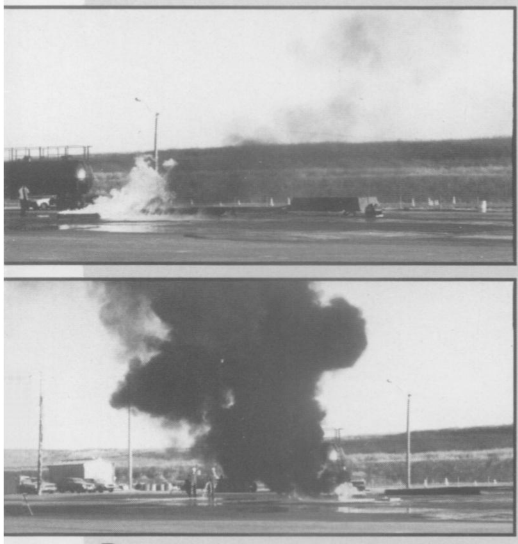
The new policy also says that educating the public about *in situ* burning "should be aggressively pursued" wherever this technology is considered appropriate. "Certainly, we don't want to be in a position where we have to make decisions in the heat of an environmental emergency," Keane says.

As the *Exxon Valdez* episode demonstrates, the window of opportunity for using burning as a oil clean-up tool is quite small. If policymakers wait for an accident to happen before considering the potential benefits of burning, Keane says, it may be too late to employ the technique. □

If smoke's the problem...

"If it were smokeless, I think *in situ* burning would be accepted [by the public], almost without question," asserts Edward J. Tennyson, the oil-spill-response program manager for the U.S. Minerals Management Service. And clean-burning oil fires may soon be not only possible, but also affordable, says Michael E. Moir of Imperial Oil Ltd.'s research and technology division in Calgary, Alberta.

About four years ago, his lab began investigating ferrocene. Originally used as a combustion enhancer for solid rocket fuel, this organometallic compound today is added to home-heating oil in Europe and Canada to reduce a boiler's sooty emissions. Moir decided to see if ferrocene could similarly whiten the smoke from burning oil slicks.



Burning oil on water with ferrocene derivative (upper) – and without (lower).

M.E. Moir/Imperial Oil Resources Ltd.

And in laboratory tests where he mixed about 2 percent ferrocene (by weight) into crude oil prior to burning, soot levels in the smoke dropped dramatically – up to 90 percent, depending on the type of oil. The additive also reduced production of polycyclic aromatic hydrocarbons (PAHs), a class of combustion pollutants that includes many known carcinogens.

Ferrocene "has shown tremendous potential for use under particular conditions," Tennyson acknowledges. But because it does not work equally well with all hydrocarbons, he suspects customized ferrocene recipes may need to be developed for individual oils.

Moir, however, downplays the difficulty of coping. "Ferrocene's not all that sensitive to an oil's hydrocarbon composition. You might see a reduction of plus or minus 20 percent."

Other skeptics point to a potentially more serious problem: how to mix the additive into slicks floating on the ocean. Ferrocene, a solid, dissolves poorly in oil. To get around the problem, Moir spent much of the past year developing more soluble derivatives. And the best of these works well, he told SCIENCE NEWS, "though the stuff is pretty expensive" – about $300 per kilogram, or 10 times the price of pure ferrocene.

"So our work is now turning back to ferrocene," Moir says. It appears the additive will blend into the oil if dispersed evenly as small particles. To that end, he has just begun developing a delivery system to spray micron-size grains of ferrocene onto an oil slick, much as farmers spray atomized pesticides onto their crops.

"Give me a few months," Moir says, "and I'll probably have the problem worked out." –*J.A. Raloff*