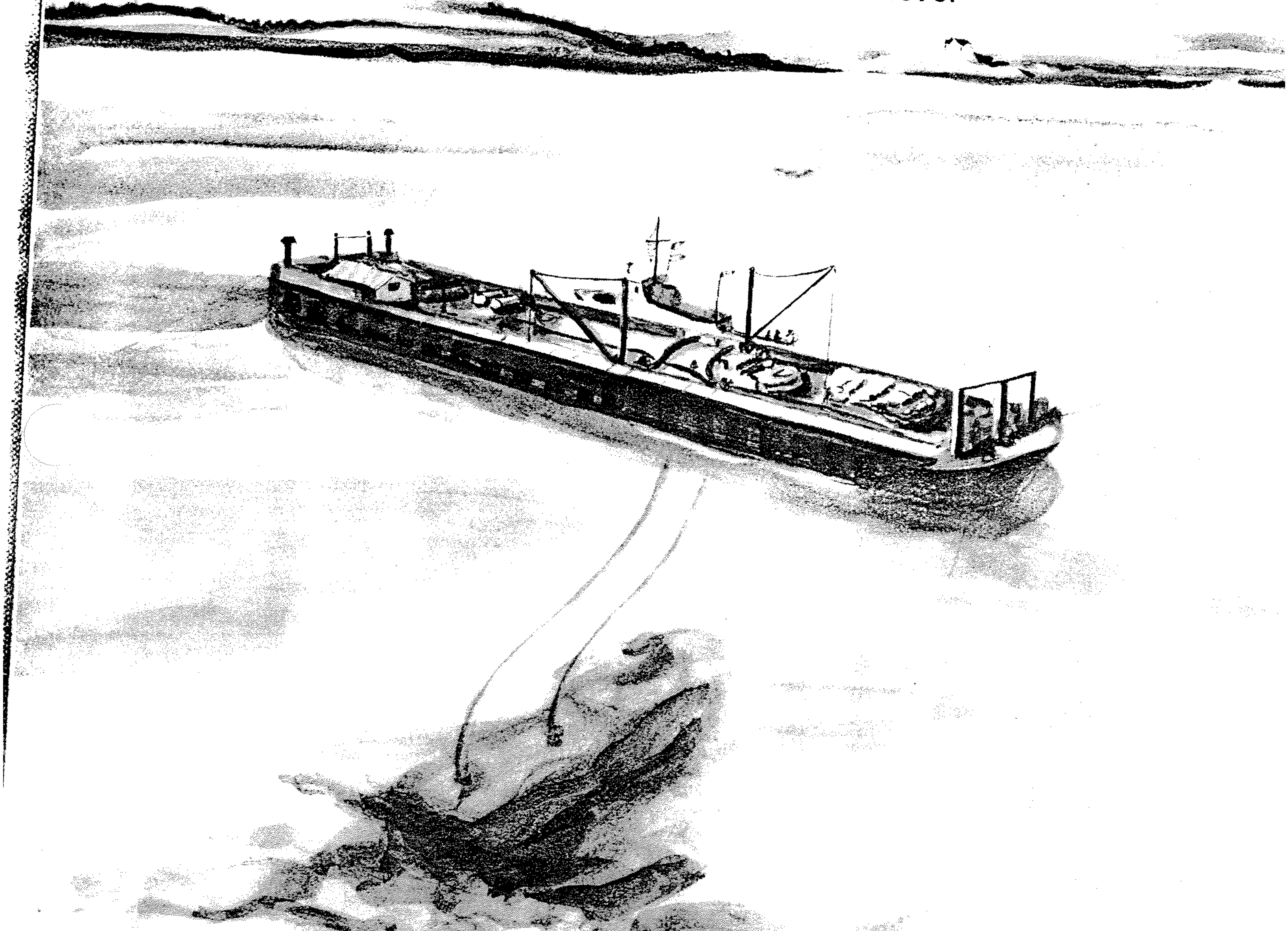
ARROW

NAVSHIPS 0994-008-1010

The recovery of Bunker "C" fuel oil from the sunken tanker, SS ARROW and concurrent measures used to control oil pollution in Chedabucto Bay, Nova Scotia, during the winter of 1970.



Department of the Navy
Naval Ship Systems Command
Washington, D.C.

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The recovery of Bunker "C" fuel oil from the sunken tanker, SS ARROW and concurrent measures used to control oil pollution in Chedabucto Bay, Nova Scotia, early 1970.

Department of the Navy
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DEPARTMENT OF THE NAVY
NAVAL SHIP SYSTEMS COMMAND
WASHINGTON, D. C. 20360

FOREWORD

The loss of a ship is always a disaster. When such a loss also releases great quantities of fuel oil to pollute the sea and shore, the consequences of the disaster reach far beyond the ship itself. The grounding of the oil tanker SS ARROW in February 1970 in Chedabucto Bay, Nova Scotia, and its sinking a week later was such a disaster. More than 2 million gallons of Bunker "C" fuel oil escaped from the tanker, ravaging maritime life and the beaches of the bay. Another 1.5 million gallons remained trapped in the ARROW's cargo tanks threatening, like a pollution time bomb, still more extensive damage.

The Supervisor of Salvage was privileged to participate in the remarkable salvage effort that was made in the ensuing weeks to recover the remaining oil from the wreck. Salvage tasks have historically been undertaken to recover cargo for its intrinsic value. This effort had nothing to do with the value of the ARROW's cargo per se. It had to do with the preservation of what this cargo could damage or destroy if allowed to escape. It was an effort made under highly adverse conditions and against long odds. It succeeded in its purpose of preventing further pollution.

The emphasis in this report is on the technical methods used in recovering the Bunker "C." The methods themselves are largely conventional and familiar, but their application in salvaging highly viscous fuel was unprecedented. As far as is known, this is the first operational experience of debunkering a sunken tanker under such conditions. The report covers all aspects of the salvage operation. It also presents information on the measures undertaken ashore to contain and control the oil spill and mitigate its effects.

The information on technical methods and procedures in this document will add significantly to the storehouse of professional knowledge in the salvage and diving communities. There is much that can be learned by studying what this salvage force did in this particular set of circumstances. It is also important to appreciate how this force was formed. The Canadian Government drew upon its own civilian and military resources, upon technical and scientific expertise available in its private sector, and, through the Supervisor of Salvage, upon the salvage capabilities of the Murphy Pacific Marine Salvage Company, an American firm. It also designated a highly qualified member of the petroleum industry as the on-scene commander of the oil recovery effort.

This force, hastily assembled and provisionally organized, could have succeeded only through the effective cooperation of civilian and military personnel, both Canadian and American, and their willingness to work together and profit from each other's knowledge and experience. This is, in fact, what happened, and the elimination of the threat of further pollution from Chedabucto Bay is compelling evidence of the effectiveness of their combined professional efforts.

E. B. MITCHELL
Captain, USN
Supervisor of Salvage, U.S. Navy

ABSTRACT

On 4 February 1970, the oil tanker SS ARROW, carrying almost 17,000 tons of Bunker "C" fuel oil grounded in Chedabucto Bay, Nova Scotia. Approximately 10,000 tons of oil escaped from the tanker, contaminating the water and beaches of the Chedabucto Bay area. The ARROW subsequently broke in two and sank. Over 6,000 tons of oil remained trapped in its cargo tanks, threatening further pollution.

The Canadian Government assembled a task force to conduct salvage operations to recover the Bunker "C" from the wreck and, concurrently, to deal with the oil which had already escaped. The salvage group developed a steam supported pumping system to recover the oil and used a hot tap technique, adapted from oil refinery procedures, to penetrate the ARROW's cargo tanks and install the necessary fittings for pumping operations. Steam traces were inserted in the salvage hoses to heat the high viscosity fuel oil. The salvage operation was centered around a large oil transfer barge which was moored over the wreck to serve as a lighter and pumping platform. The techniques and equipment used to outfit the barge and prepare it for the oil recovery effort were a notable feature of the salvage operation. A wide variety of measures, mostly mechanical, were used to control the spilled oil and clean the beaches and coastlines. The success of the salvage and clean up operations resulted, in large measure, from the effective cooperation of civilian and military personnel, both Canadian and American.

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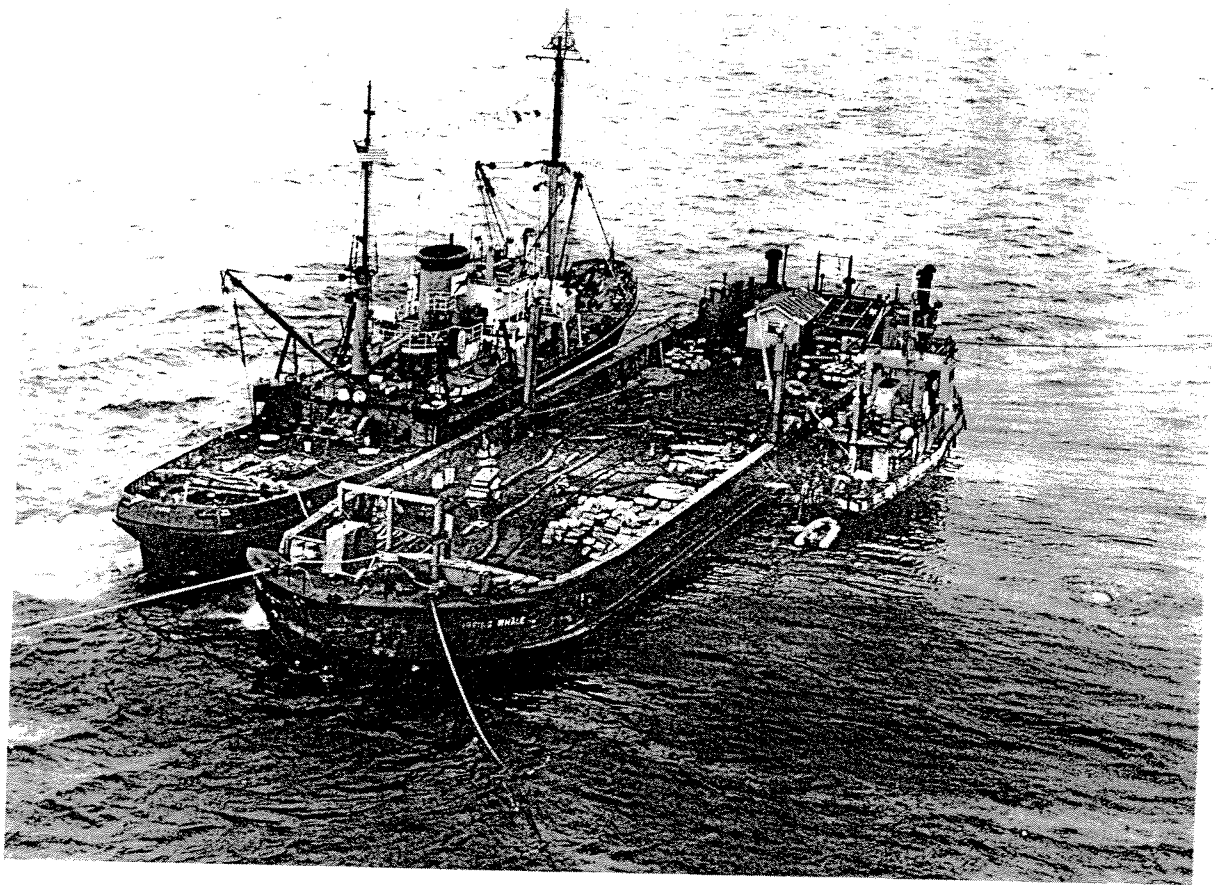


Frontispiece. Salvage Operations in Chedabucto Bay, Nova Scotia. The Oil Transfer Barge, IRVING WHALE, with the U.S. Navy Salvage Ship, CURB, and the Royal Canadian Navy Diving Tender, YMT-12, Alongside.

INTRODUCTION

This report is designed to give the reader a detailed understanding of the salvage effort conducted in Chedabucto Bay, Nova Scotia during the winter of 1970 to recover Bunker "C" fuel oil from the sunken tanker, SS ARROW. This salvage effort was part of an overall undertaking by the Canadian Government to control and minimize oil pollution resulting from the wreck. The operation as a whole is presented in sufficient detail to provide a general understanding of the related measures that were applied to control the pollution.

It is often observed that no two salvage jobs are exactly alike. But it is also important to remember that no single salvage job is completely unique. A successful salvage effort is invariably the product of adapting techniques and equipment to different circumstances. It is the knowledge derived from the solution of previous problems which enables salvors to attack new problems. Such is the case with the ARROW operation. The ARROW salvage job may never be duplicated. It is certain, however, that the knowledge gained by its participants can be usefully applied in the solutions of similar problems in the future. This knowledge is available in this report.

THE LOSS OF THE ARROW

The SS ARROW entered Chedabucto Bay, Nova Scotia, early on 4 February 1970, nearing the end of a routine passage from Aruba, an island off the coast of Venezuela. Chedabucto Bay (figure 1) lies about 700 miles northeast of New York City and about 150 miles northeast of Halifax, Nova Scotia's principal city. The bay, along with the Strait of Canso and George Bay on the western coast, forms part of the body of water that separates Cape Breton Island from the main peninsula of Nova Scotia. Remote, sparsely populated, and formerly partially ice bound in winter, the Chedabucto Bay region (figure 2) has historically been and remains today principally a commercial fishing area.

The ARROW, a Liberian registry oil tanker, was carrying about 16,000 tons of Bunker "C" high viscosity industrial fuel oil, destined for Port Hawkesbury, Nova Scotia. Owned by the Sun Navigation Company, the ship was under charter to the Imperial Oil Company. The latter company, which has offices and facilities in Halifax, had sold the ARROW's cargo to a paper company in the Point Tupper area.

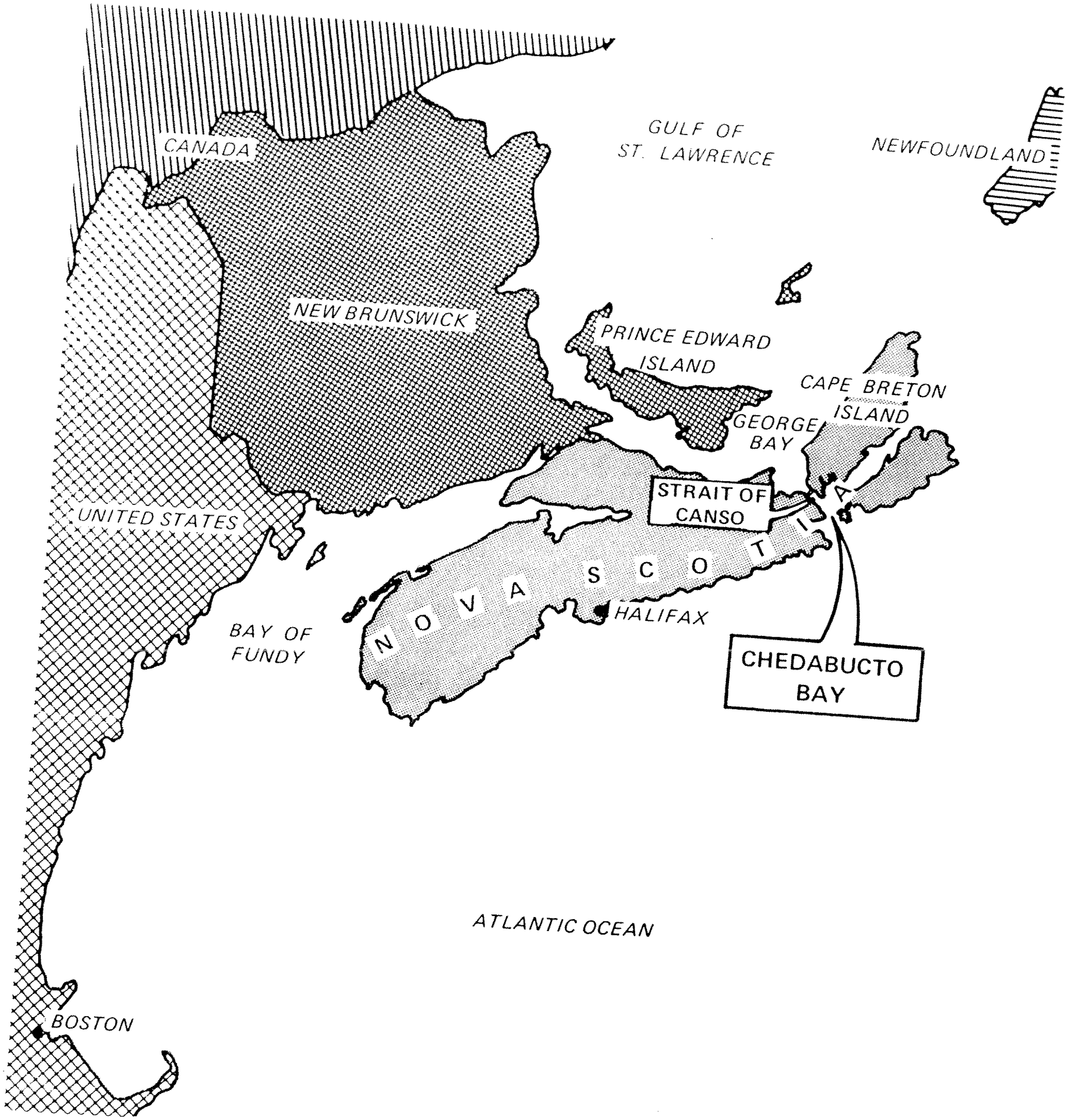


Figure 1. Location of Chedabucto Bay, Nova Scotia.

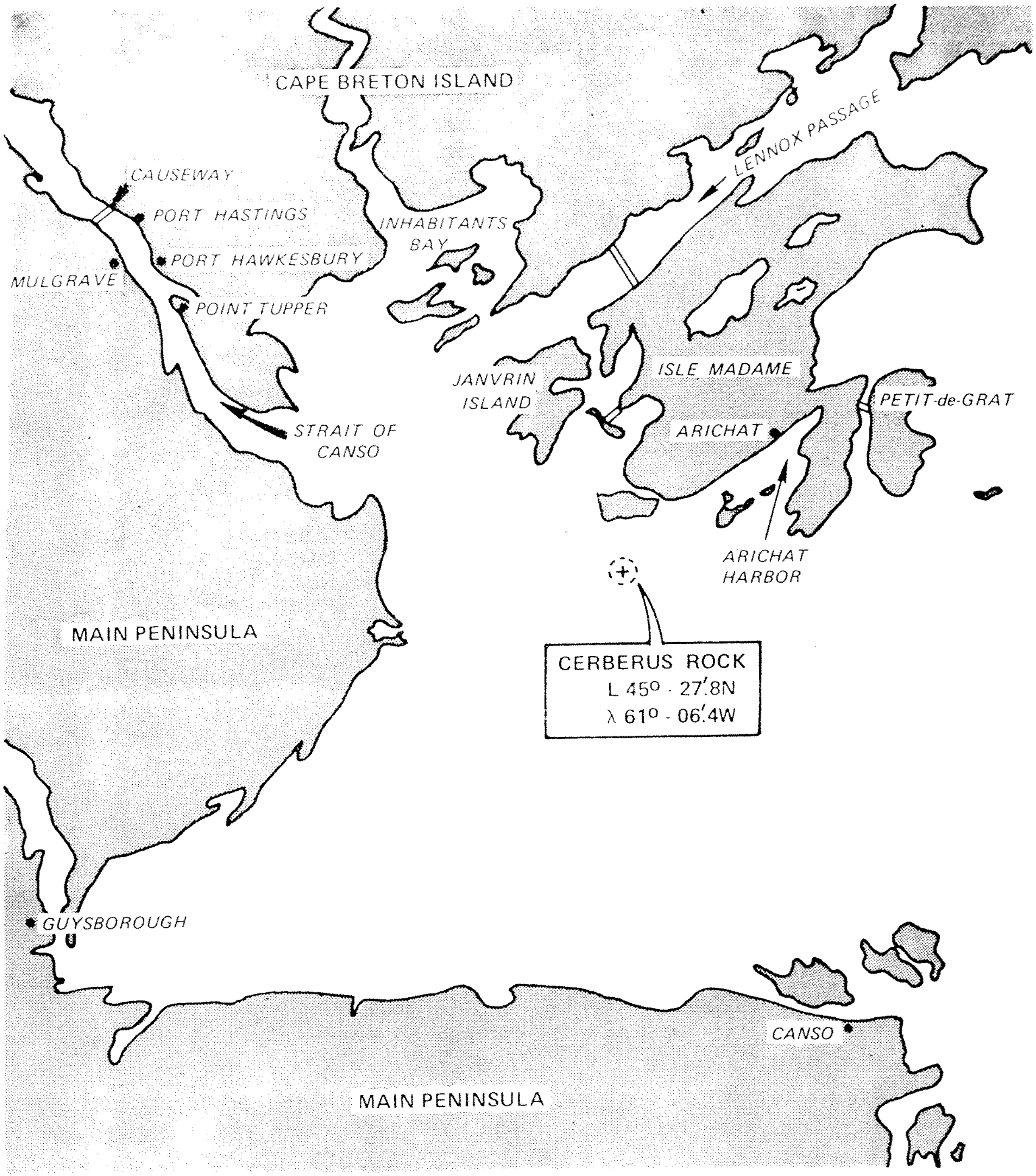


Figure 2. Chedabucto Bay, Nova Scotia.

GROUNDING ON CERBERUS ROCK

If the run from Aruba was routine, the weather in Chedabucto Bay was not. The tanker encountered 60-knot southwesterly winds and heavy mist as it crossed the bay heading for the entrance of the Strait of Canso. The ship smashed into Cerberus Rock in mid-morning, about halfway between high and low tide. Cerberus Rock lies to the north of the normal channel approaches to the Strait of Canso, approximately 4 miles south of Arichat, the principal built-up area on Isle Madame. The rock formation is a well known navigational obstruction in the bay and is charted appropriately as a navigational hazard. At low water it is awash and readily visible in clear weather. Since the tidal range is only about 5.5 feet, it is also identifiable at high tide by water breaking over the rock and the eddies created about it. Deep water (minimum 10 fathoms) surrounds the rock.

The impact of the grounding drove the forward section of the tanker into the rock formation wedging it with the starboard side hard against the rock pinnacle. Impaled on the rock, the ARROW's life was essentially over, although this fact was not evident initially either to its captain or to the salvage personnel who first came to its aid. The ship settled on a relatively even keel and appeared in no immediate danger. Its skipper notified the Canadian Department of Transport (DOT) at Halifax shortly after 1100 that no assistance was required. However, the weather grew worse during the afternoon and DOT dispatched the Coast Guard cutter, NARWAHL, to stand by near the stranded tanker. The Imperial Oil Company went on an oil spill alert and initiated arrangements for salvage operations. Most of the ARROW's crew were taken off the ship late that night, leaving a skeleton force aboard.

BREAKUP AND SINKING

Vulnerable amidships where the #5 cargo compartment was empty, the ARROW's back was soon broken by the pounding of the seas. The ship was dying on the rock. This became evident within a few days when the deck plates and side plating began buckling. The tanker finally split into two sections on 8 February.

The initial salvage efforts focused on the recovery of the severed stern section. These attempts, hampered by heavy weather, finally failed on 12 February. Tugs could not control the stern section and it sank in an upright position in 90 feet of water about 600 yards north of the rock. The bow section had also gone under by this time, remaining near the rock in shallower water. Both the ARROW's funnel on its stern section and the upper part of its bridge structure on its forward section remained awash (figure 3).

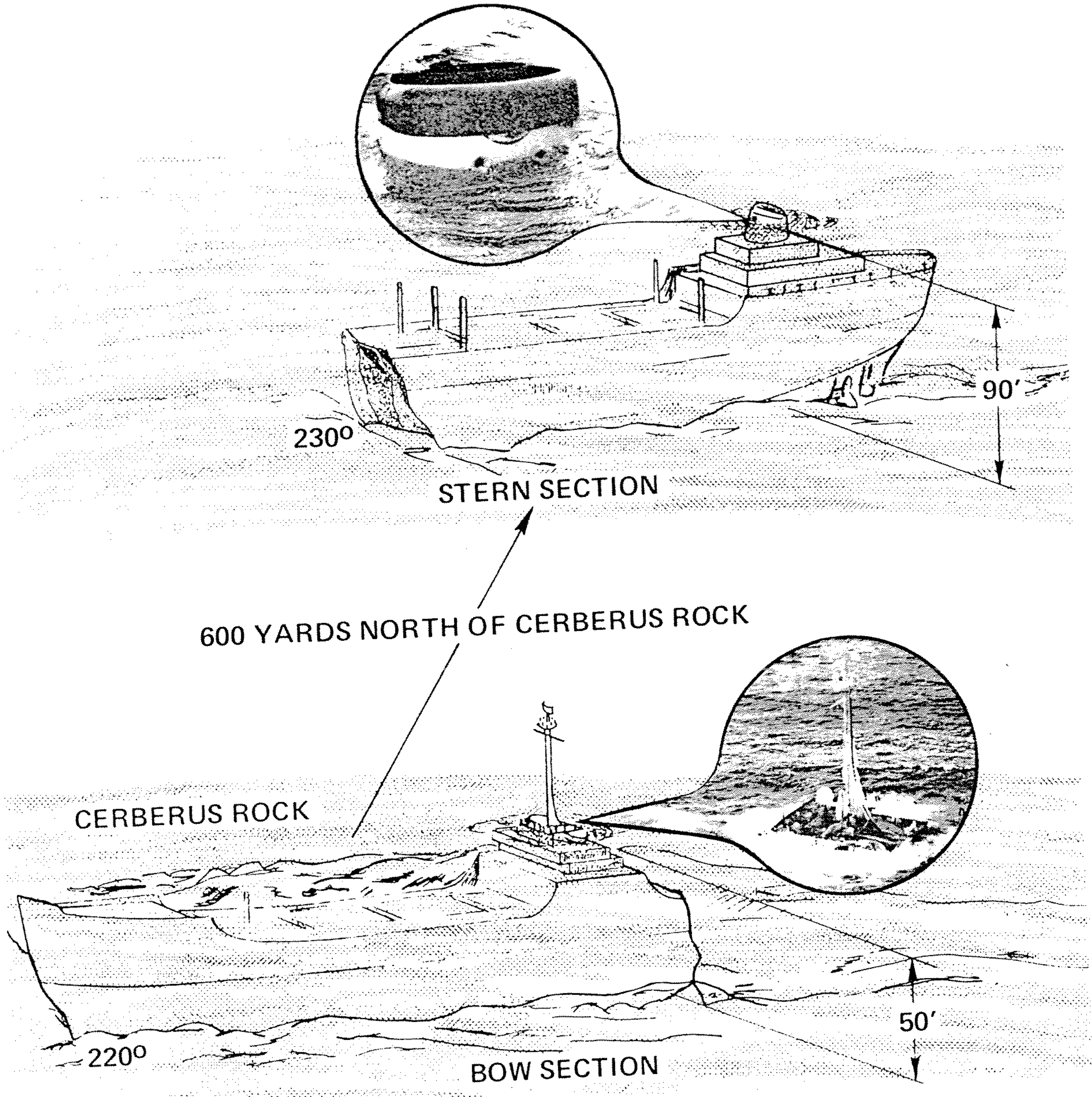


Figure 3. The ARROW, Broken in Two Sections, on the Bottom of Chedabucto Bay.

DAMAGE ESTIMATES

A detailed divers' survey of the wreck was not made until a few weeks after the ARROW had split and sunk. The survey revealed what had generally been suspected concerning the extent of damage. The bow section was badly smashed while the stern section, on the other hand, remained essentially intact. Both sections were hard aground. Oil had escaped from cargo tanks in both sections.

The bow section, wedged by rocks, was lying on a general 220° heading, listing about 20° to starboard with a slight trim aft. Its starboard side was crushed from the bridge structure to the forecastle break, the crushed area extending from the bottom to within 6 to 8 feet of the deck in the vicinity of the #2 starboard wing tank. The crushed area tapered downward from this point to within a few feet of the bottom at both ends of the bow section. All cargo tanks appeared open to the sea with the possible exception of two portside wing tanks. The deck itself was in shambles, having split open along both sides of the catwalk. The hull was completely broken and open aft of the bridge structure.

The stern section had suffered relatively little damage. Divers reported that it was resting on a firm gravel bottom with little or no list or trim. The hulk was lying upright in a southwest/northeast direction. Seven cargo tanks appeared intact. Although oil was seeping from several vents and pipelines, the wreck seemed realtively secure. It was not being subjected to the buffeting of surface waves which was threatening to break up the bow section. The stern section was also in a reasonably accessible position for diving and salvage operations. The deck was about 55 feet below the surface and the nearest navigational obstruction was Cerberus Rock, 600 yards to the south.

CHARACTERISTICS OF THE CHEDABUCTO BAY AREA

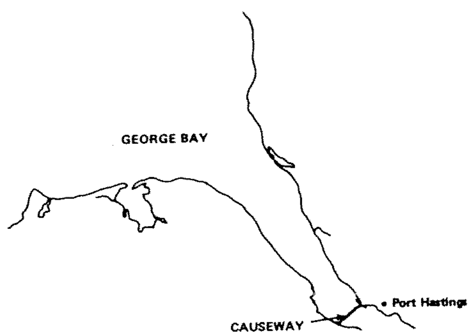
IMPORTANCE OF THE FISHING INDUSTRY

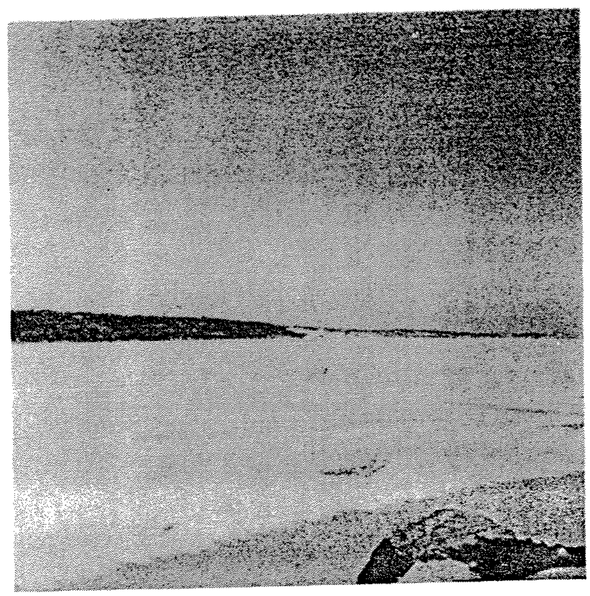
The life of Chedabucto Bay and its people depends heavily on the fishing industry. Consequently, the potential effects of a massive oil spill on marine life became a matter of immediate major concern to the Canadian government. Fishing and fish packing are the main commercial activities, with lobster and herring the principal fish of economic harvest. Clamming is also important but as a local food supplement caught by individual fishermen rather than as an organized business enterprise. Most of the people in the Chedabucto Bay area earn their living directly from the fishing industry, either as fishermen or by working in the various fish plants around the bay. The Canadian Department of Fisheries is the most prominent federal government activity in the vicinity.

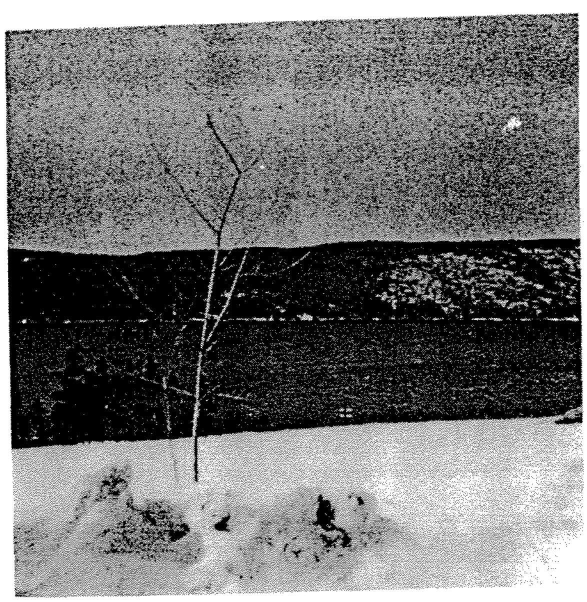
INDUSTRIAL POTENTIAL

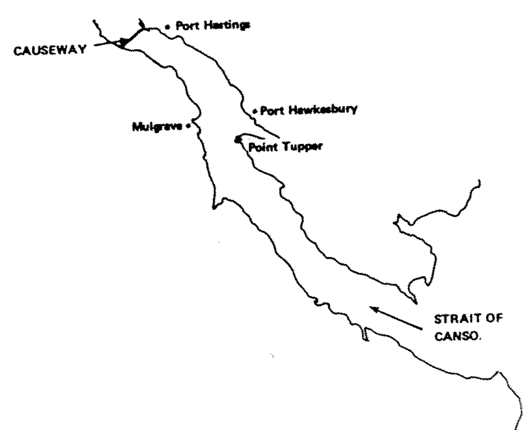
A 210-foot-deep causeway across the Strait of Canso at Port Hastings connects Cape Breton Island with the main peninsula. The causeway, constructed in 1955, did more than just provide an overland transportation link; it also freed the strait and bay areas from ice during the winter months (figure 4). This, in turn, has created one of the few year-round deep water ports in Canada, a harbor complex of vast industrial potential. The Canso causeway formed an ice-free harbor 14 miles long and more than 120 feet deep. The strait is wide enough at the southern end to allow most ships to turn on their own power. It is an area that has become particularly attractive for the petroleum industry because of its access capabilities for tankers and super tankers. Although the fishing industry is still the main commercial activity, it is probable that the Chedabucto Bay area will be the site of significant industrial development in the future.

Ice bound in winter above the causeway.









Open for year round deep water operations below the causeway.

Figure 4. Effects of the Causeway Across the Strait of Canso.

FACILITIES ASHORE

The major port facilities are located along both sides of the Strait of Canso, south of the causeway. Port Hawkesbury and Port Hastings on the northern side of the strait form a twin-port complex. The population of these two cities approaches 12,000. A shipyard is located at Port Hawkesbury. Across the strait, the town of Mulgrave, about 8,000 people, also has port facilities. The principal support activities for the salvage operation were mounted from these areas.

Arichat, a small fishing village on the southern side of Isle Madame, also played an important role in supporting the salvage operation. Only a few miles from Cerberus Rock, its small harbor served as a haven to the diving tender and other vessels of the salvage force. Inhabitants Bay, near the southern entrance to Lennox Passage, also provided anchorage areas in emergencies.

PRESENT COMMERCIAL ACTIVITIES

Industrial development in the bay is relatively new, resulting in part from the opportunities made available from the construction of the causeway. The Point Tupper complex is the site of most new industrial activity. Facilities include a pulp mill that is undergoing expansion, a generating plant of the Nova Scotia Power Commission, a bulk chemical company, and a heavy water plant operated by the Canadian Government. Gulf Oil Canada Ltd. is constructing a 60-million-dollar petroleum refinery that will be among the largest in Canada. The first dock in the Western Hemisphere capable of handling 326,000 ton tankers is expected to be ready for operations before the end of 1970. Other installations are planned for the future. In addition to these industrial activities, there is some mixed farming in the area and the beginnings of a tourist trade, particularly in the resort area of Guysborough Harbor on the southern side of the bay.

CLIMATE AND WEATHER

Chedabucto Bay is approximately along the same latitude as Bangor, Maine, and Seattle, Washington. Its climate, although severe in the winter months, is surprisingly mild during the rest of the year. The principal feature of its weather during the winter season is not so much low temperatures as the prevelance of winter storms and gales. The weather during this part of the year is highly erratic and the bay area is subjected to high winds, sleet, rain, snow, mist, and ice storms. All these weather conditions were experienced by the salvage force at various times throughout the operation. Southwesterly gales sweeping up from the northeastern coast of the United States and low fronts moving westward from the Great Lakes Basin account for the majority of winter storms. Sea states are generally not difficult for navigation in spite of the varying winter weather conditions.

OPERATIONAL SITUATION, 4–12 FEBRUARY

The Imperial Oil Company reacted immediately to the grounding of the ARROW on Cerberus Rock on 4 February. Efforts were made initially to remove the cargo that had not been spilled and, subsequently, to salvage the stern section after the ship broke in two. Locally available salvage companies were engaged for the latter purpose. Concurrently, the Imperial Oil Company implemented its oil spill contingency plans in an attempt to deal with the oil that had escaped from the wreck.

INITIAL SALVAGE ATTEMPTS PRIOR TO SINKING

Efforts to Transfer the ARROW's Cargo

When the Imperial Oil Company first learned of the tanker's grounding, it dispatched one of its coastal tankers, the IMPERIAL ACADIA, to take off the ARROW's cargo. It was assumed that this could be done by using the ARROW's steam system to heat the remaining Bunker "C" in its cargo tanks to the minimum of 135°F required for pumping. However, the ARROW's fires had been permitted to die down and neither the salvage force nor the ship's crew members were successful in their attempts to restore the steam. The steam lines had evidently been wrenched and broken in the convulsions of the ship.

Plans to Salvage the ARROW's Stern Section

The bow section appeared beyond salvage when the ARROW broke into two sections. It was hoped, however, that the stern section could be recovered. Two salvage tugs wrenched it free of the bow section to minimize further damage. The tugs then tried to keep the stern section into the sea, although no attempt was made to anchor it to help maintain its position on the rock and thereby prevent premature refloating or slipping off the ledge.

A salvage plan to recover the stern section was devised by marine architects. The #7 and then the #6 center cargo compartments would be dewatered, using compressed air. This would be sufficient to refloat the stern section. An oil boom would contain the oil blown from the tanks and dispersants would be used to remove the oil. The stern section would then be towed to sea, about 400 miles, and disposed of past the 1000-fathom curve, or, if the Bunker "C" appeared securely contained, the hulk would be towed to a safe anchorage and its cargo offloaded.

Salvage planning was hindered by the fact that curves of form for broken ships were not available and had to be extrapolated. As a result planning had to proceed based on partial and largely theoretical data. Furthermore, the ship could not possibly float if it slipped off the rock before the two tanks were blown; the forward part of the stern section would not be sufficiently buoyant to keep the ship from upending. Upending would submerge the engine compartments and sink the hulk. In addition, the number of readily available pumps appeared insufficient. This, combined with the sludge-like oil, added to the difficulty of the operation.

Attempts to implement the salvage plan were terminated when the ARROW's stern section sank on 12 February. Attention shifted from devising methods to float the hulk to devising methods to recover the Bunker "C" still contained in the ship's cargo tanks, before further spillage and pollution could occur.

IMPACT OF THE OIL SPILL ASHORE

The amount of Bunker "C" that escaped from the ARROW approached 2.5 million imperial gallons. The bulk of the oil apparently spilled within the first 24 hours after the tanker first hit Cerberus Rock, most of it from the smashed bow section. Although the visible damage to the stern section was much less, it is evident that a great quantity of oil also escaped from this part of the ship, however, probably at a slower rate. Steam and oil pipelines throughout the ship were wrenched and broken and some of the cargo undoubtedly escaped through these openings. Fuel oil that did not spill immediately continued to be released throughout the first week as the ship broke up and finally sank.

The oil spill contingency plans of the Imperial Oil Company were implemented the day after the grounding. These plans called for containment, abatement, and finally clean up. Heavy seas precluded any attempt at containment. Therefore, Imperial Oil Company personnel concentrated on abatement, i.e., preventing the oil from reaching critical points and dealing with it in the water.

A mile-long oil slick formed on 5 February, headed toward Cape Breton Island, the northern side of the bay. Booms were rushed from Halifax and Boston and deployed across three fish plants in the area. Several light aircraft dropped a chemical dispersant (COREXIT) on the slick with little visible success. The oil continued to spread, washing up on the shores of Isle Madame in the vicinity of Arichat Harbor. Shifting winds a few days later pushed some of the oil southward, eventually landing it on about 10 miles of beach around Canso on the southern side of Chedabucto Bay. Effects of the oil spill are shown in figures 5 and 6.

Within the first week the invading fuel oil had occupied almost 75 miles of beachheads on both sides of the bay and was threatening to penetrate Lennox Passage separating Isle Madame from the main island of Cape Breton. The full extent of the pollution was not immediately apparent as heavy snowfalls obscured much of the oil on the shores. It was clear, however, that the polluted beaches presented a formidable task for the cleanup forces being deployed into the area by the Canadian Government. The oil was described by various observers as "globular masses," "goop," "tooth paste," and "sludge." The oil that was still in the water caused even greater concern than that which had already washed ashore. Both scientists and laymen feared that the polluted waters would threaten the livelihood of the people engaged in the fishing business, largest industry in the area. The start of the spring fishing season was little more than a month away.

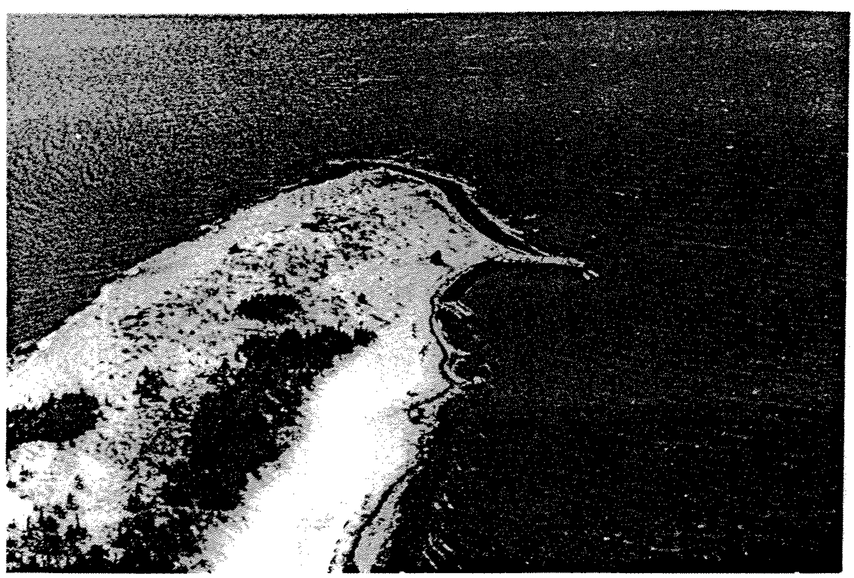
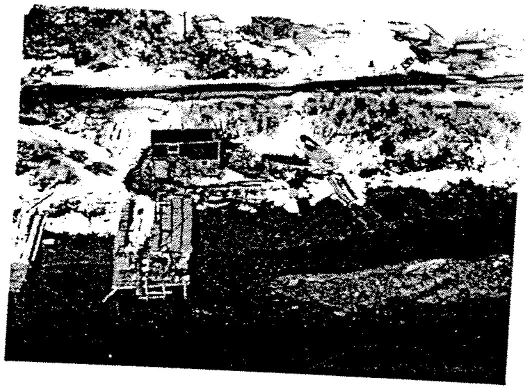
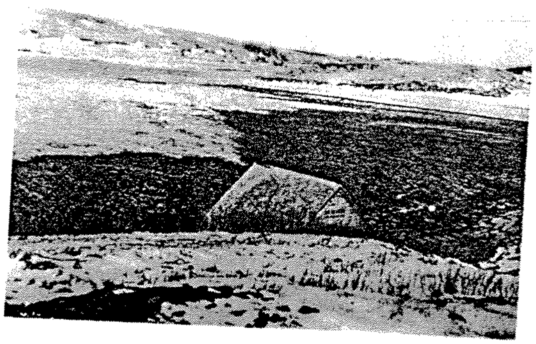


Figure 5. Bunker "C" Invading the Waters and Beaches of Chedabucto Bay.



Oil engulfs lobsterman's landing near Arichat.

Abandoned pier near Canso.



Iced-over oil slick.

Rock fill infested with Bunker "C."

Figure 6. Views of Bunker "C" Polluting the Shores of Chedabucto Bay.

SCOPE OF THE SALVAGE PROBLEM

The breakup of the ARROW and the sinking of its stern section on 12 February presented the Canadian Government with a salvage problem of an entirely different nature. A detailed survey of the wreck over the next few weeks revealed the full dimensions of the problem. The characteristics of the Bunker "C" fuel oil, the large quantities to be recovered from many different cargo tanks, and the weather conditions expected in Chedabucto Bay all indicated that recovering the ARROW's cargo would be a difficult undertaking.

SALVAGE SURVEY

The amount of spilled oil and that remaining in the wreck could not be determined with precision. Although it was established that the ARROW was carrying about 110,000 barrels of oil when it hit Cerberus Bock, it was not clear just how this load had been distributed among the various cargo tanks. In addition, there was no known method for measuring the amount of oil left in each tank. The salvage master developed an estimate of the quantities of oil involved. This estimate was based on his detailed knowledge of the ship's construction, on divers' reports of the damage to each tank, and on divers' observations of oil discharge when the ullage covers were opened.

Amounts of Bunker "C"

The amounts of Bunker "C" estimated to have spilled and to be remaining in the wreck were as follows:

	Imp. Gallons	Barrels*	Tons**
ARROW's Cargo	3,850,000	110,000	16,923
Amount Spilled	2,350,000	67,150	10,330
Remaining in Wreck	1,500,000	42,850	6,593

* 1 barrel = 35 imp. gallons

** 1 ton = 6.5 barrels

Location of Bunker "C" in ARROW's Cargo Tanks

The ARROW had nine major cargo compartments. Each compartment was subdivided longitudinally to form three cargo tanks, those in the center of the ship being approximately twice the capacity of their respective port and starboard wing tanks (figure 7).

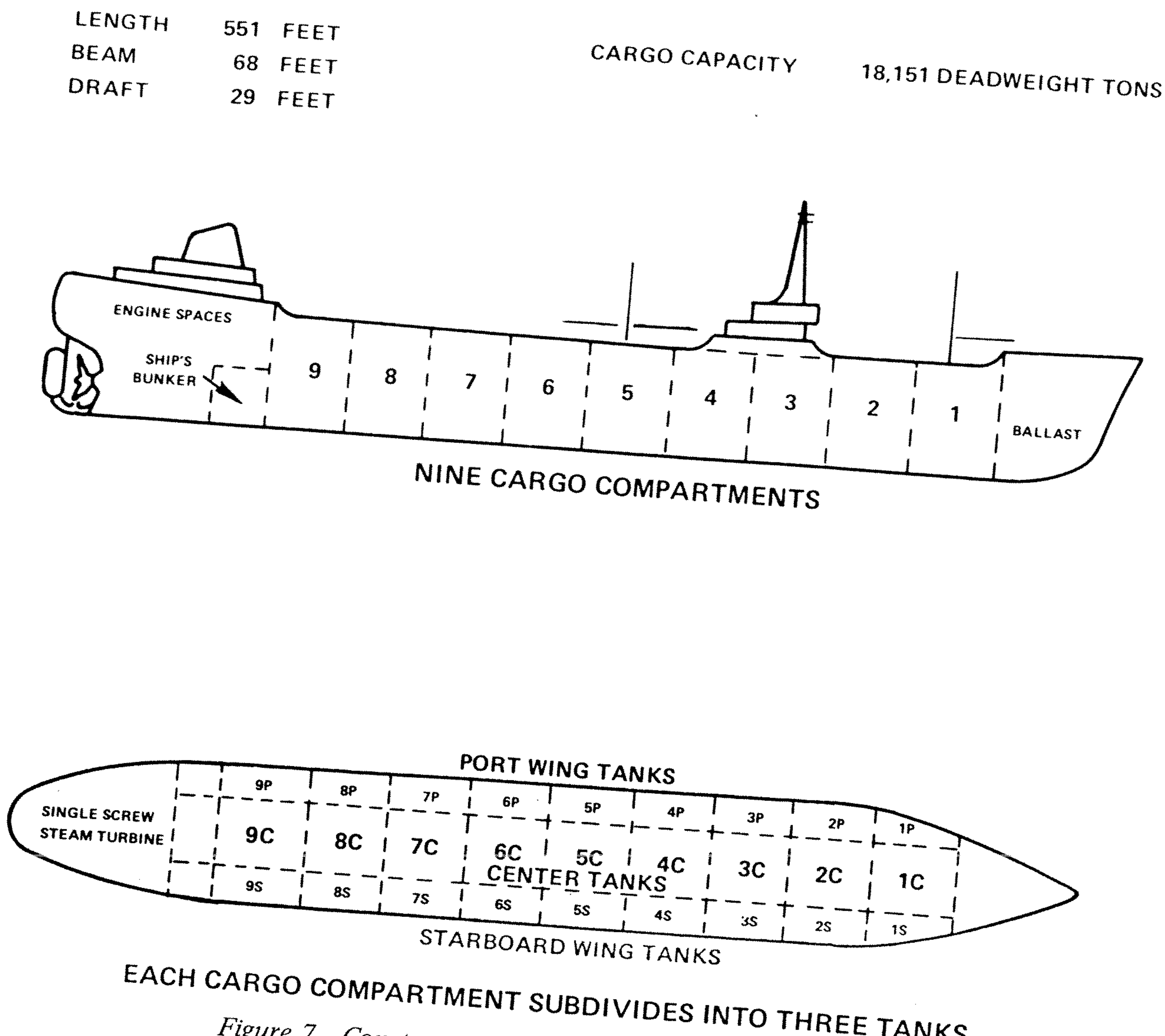


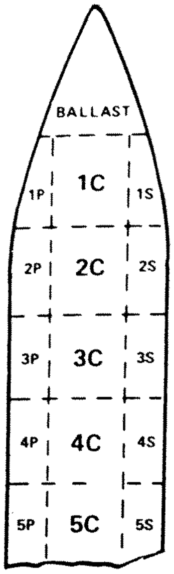
Figure 7. Construction of the Oil Tanker, SS ARROW.

It was established that the amidships, or #5 cargo compartment, was empty before the ship went aground. The salvage master assumed that the cargo was generally spread evenly throughout the remaining compartments. He proceeded with salvage planning on the basis that the ARROW had been carrying about 1000 tons in each of eight center tanks and about 500 tons in each of 16 wing tanks. The condition of each cargo tank, as it appeared to the salvage master on 27 February, is shown in figure 8.

Related Considerations

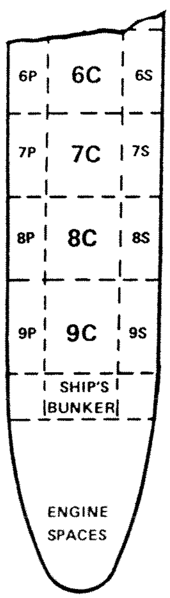
In addition to the cargo tanks, it was also necessary to consider the ship's fuel oil that was carried aft in the ship's bunker. The bunker was flanked by two settling tanks that also had to be checked for oil. It was probable, however, that the ARROW had already consumed most of

SITUATION IN BOW SECTION



1P, 1C, 1S 2P, 2C, 2S 3P, 3C, 3S	These three cargo compartments ruptured. Wing tanks on port side may still have some oil in a wedge effect only. Residual only in center and starboard tanks.
4P, 4C, 4S	Little or no oil left. Tanks ruptured on grounding. Remaining oil probably escaped when ship broke.
5P, 5C, 5S	Empty on trip; now completely open to sea, dividing bow and stern sections.

SITUATION IN STERN SECTION



6P, 6C, 6S	Port and center tanks flooded when ship broke; now open to sea. Starboard tank may still have oil.
7P, 7C, 7S 8P, 8C, 8S	All tanks in these two cargo compartments appear tight and full of oil.
9P, 9C, 9S	Tank covers open and no oil remaining in wing tanks. Center tank appears tight and full of oil.
Bunker & Settling tanks	Appear intact; amounts of fuel oil in these tanks unknown.

Figure 8. Condition of ARROW's Cargo Tanks as Reported on 27 February.

its fuel before it went aground. The ship was about to enter port and it was apparently a routine practice to carry only enough fuel for the voyage plus three days reserve supply on runs of this type from Aruba.

The condition of the ship's bottom under the cargo tanks still containing oil was an important factor. The hull evidently had been pierced under these tanks when the ship sank. They were open to the sea at the bottom. Sea water had entered the tanks, forcing the oil upward against the tank tops. This process served both to trap the oil in the tank and to help make it accessible for pumping operations.

CHARACTERISTICS OF BUNKER "C" FUEL OIL

Bunker "C" is a heavy residual fuel oil of exceptionally high viscosity, similar to Number 6 commercial grade burner fuel oil. It is one of the cheapest fuel oils produced, and is normally used in large scale heating installations equipped with preheaters. Like other heavy tars and asphalts, it does not distill over in the fractionalization/distillation process. Instead, it is taken off the bottom of the column; hence, it is in the general category of residuals as distinct from distillates.

Bunker "C" was the standard main propulsion boiler fuel for U. S. Navy ships prior to World War II. It was replaced in the early 1940's by Navy Special Fuel Oil (NFSO). NFSO, although also a residual, was made from higher quality components and was diluted to desired viscosity by distillate stock. Consequently, it performed better than the heavier Bunker "C".

The viscosity of the ARROW's cargo was 280 seconds (SSF) at 122°F according to the manufacturer's specifications. There was no meaningful way to measure or calculate its actual viscosity as it lay in the wreck, its temperature close to freezing. The viscosity of fuels of this type increases radically as temperature decreases. The increase is so radical that normal viscosity-temperature tables do not attempt to show viscosity measurements at temperatures lower than 70°F. The viscosity of the fuel oil in the wreck, given a temperature of 35°F, no doubt exceeded 1000 seconds (SSF). Therefore, there was good reason to believe that the oil simply could not be pumped under such conditions.

IMPLICATIONS

The estimates of the situation as it existed in late February made it clear that a significant amount of fuel oil remained in the ARROW's hulk, an amount that, if allowed to escape, could almost double the damage already inflicted on Chedabucto Bay. The recovery of perhaps 40,000 barrels of the ARROW's cargo would require a major salvage effort.

The possible location of the oil in approximately 13 different cargo tanks would also add to the complexity of any salvage undertaking. Furthermore, the winter gales that had so disrupted the early salvage efforts in February could also be expected in March. The exceptionally high viscosity of the Bunker "C" trapped at near-freezing temperatures in the wreck's cargo tanks was a matter of great concern to the assembling salvage force. Finally, and most importantly, no one had ever recovered a cargo like the ARROW's. A great many observers, outside the salvage force itself, questioned the feasibility of the undertaking.

The position of the wreck, on the other hand, was favorable. Although in an open roadstead with varying sea conditions, it was only a few miles from shore and a salvage effort could be easily supported. The ARROW's deck was about 55 feet below the surface, not so deep that diving work would be inordinately difficult. Various proposals for extracting the oil had been submitted by both Canadian and American salvage experts. These factors, coupled with the availability of the salvage resources now being marshaled by the Canadian Department of Transport, lent credence to the hope that the job could be done before the wreck broke up and the remaining cargo escaped.

MARSHALING OF FORCES

BACKGROUND

The Imperial Oil Company, owner of the ARROW's cargo, assumed initial responsibility for the first salvage attempts prior to the final sinking of the tanker's stern section. Concurrently, its representatives took the lead in the early efforts to combat the oil spill. It was soon evident, however, that the scope of the disaster warranted immediate intervention by the Canadian Government. The Department of Transport was assigned the task of coordinating subsequent cleanup and salvage operations. Its role, at the outset, was to assemble resources to assist and expand the Imperial Oil Company's effort. As its staff capabilities in the operational area increased, it took command of the overall operation, working in close cooperation with the Department of Defense, particularly the Maritime Command, the Department of Public Works, and the Department of Fisheries.

The civilian and military resources deployed to Chedabucto Bay were organized in one centrally-directed task force (figure 9). The task force's principal responsibilities were to (1) conduct containment operations to control the spilled oil and deny it access to the beaches wherever possible, (2) initiate a salvage and debunkering effort to extract the Bunker "C" remaining in the ARROW's cargo tanks, and (3) clean beaches and jetties and dispose of the oil that had come ashore.

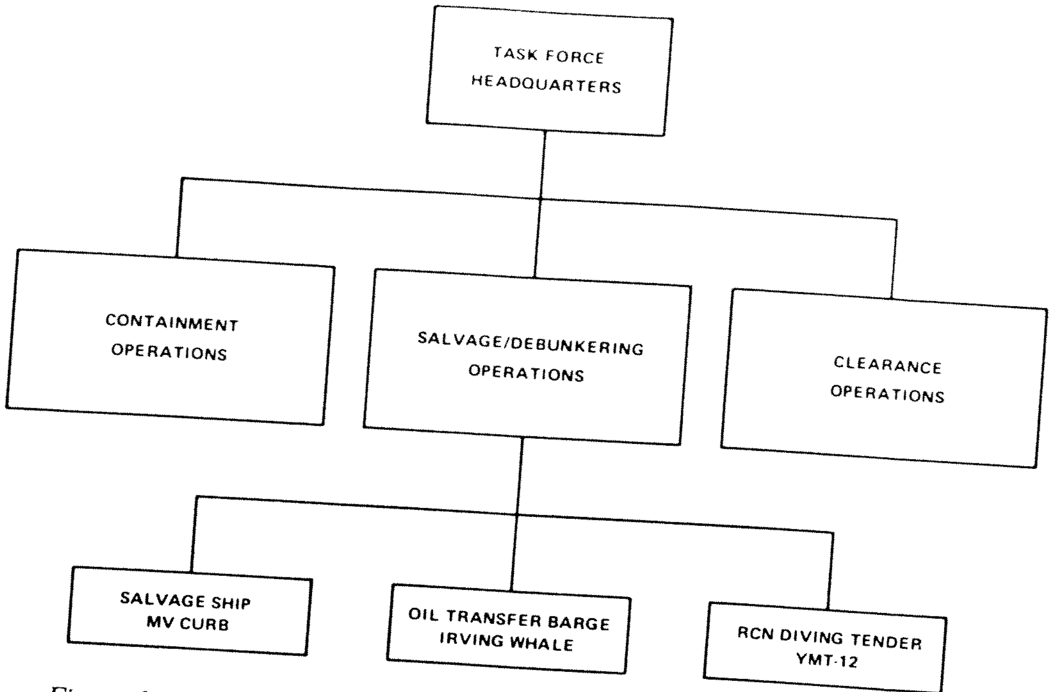


Figure 9. Organization of Task Force for Pollution Control Operations.

TASK FORCE HEADQUARTERS

The Canadian Government recognized that the oil pollution problem in Chedabucto Bay required the application of science as well as available technology. Existing knowledge of the effects of the pollution was extremely limited as was knowledge of techniques to combat it effectively. Accordingly, the Canadian Government made extensive use of Canadian scientific resources in assembling a task force to deal with the problem.

Dr. Patrick D. McTaggart-Cowan, Executive Director of the Science Council of Canada, was designated task force director. Dr. Harry Sheffer of the Canadian Defense Research Board was selected as his principal scientific advisor and Captain Micheal Martin, Royal Canadian Navy, was assigned to supervise military and naval participation. These three officials (figure 10) had the necessary scientific and technical experience to grasp the problems involved in the undertaking. Their diverse backgrounds helped to weld a close civilian-military relationship within the task force and their relatively high positions enabled them to represent the force effectively in dealings with the government, the public, and the press.

The task force headquarters, located in a motel near Port Hastings, developed a 24-hour operational capability by creating an operations control center. This center, supported by a communication detachment of 3 Signals Squadron, Royal Canadian Army, and a meteorlogical service facility, monitored all operations, ashore and afloat, on a round-the-clock basis. Staff

Dr. H. Sheffer
Scientific Advisor

Dr. P.D. McTaggart-Cowan
Task Force Director

Capt. M. Martin, RCN
Military Advisor

Figure 10. Canadian Government Officials Directing the Overall Operations.

capabilities, other than those of the operations control center, were also substantial; they included administrative personnel, a logistics and transportation group, finance experts, and public information officers (figure 11).

Operating in close coordination with the headquarters and all elements of the task force was a separately organized scientific research and advisory group. This group played an extremely important role throughout the operation. Its primary tasks were to evaluate the many proposals under consideration for dealing with the oil, to assess its impact on marine life in the bay, and to assist in the development of salvage methods. This group was staffed with scientists from the federal service of Canada, particularly the Department of Fisheries. It also had important links with Canadian laboratory facilities.

ORGANIZATION FOR SALVAGE OPERATIONS

The Canadian Department of Transport, acting through the newly designated task force director, made two critical decisions concerning the assembly of forces for the salvage effort and their organization. First, it decided to engage Captain Sven A. Madsen of Esso International of New York as the salvage master. This action, taken on 25 February, assured that the salvage operation would be headed by a person with extensive background and knowledge of oil tankers and of the characteristics of Bunker "C" fuel oil.

Secondly, on the same day, the decision was also made to arrange for the participation of the Murphy Pacific Marine Salvage Company. The Supervisor of Salvage, U. S. Navy directed the commitment of the MV CURB, a Navy salvage ship leased to Murphy Pacific. The CURB got underway immediately from New York City for the operational area. The decision to obtain the CURB's services reflected recognition by the task force that a fully equipped salvage ship would be essential if the oil recovery problem was to be solved. Captain Robert Belsher assumed responsibility for Murphy Pacific's participation, reporting directly to Captain Madsen for the conduct of salvage operations. These leaders of the salvage force are shown in figure 12.

The salvage force was organized around three principal vessels: the MV CURB; the YMT-12, an RCN diving tender; and the IRVING WHALE, an oil transfer barge. These vessels and their use in the salvage operations are described in subsequent sections.

ORGANIZATION FOR OPERATIONS ASHORE

Containment and clearance activities were conducted by both military personnel and civilian workers. The latter were provided by local contractors and the Canadian Department of Public Works. Military personnel were principally Army engineers from the Canadian Forces

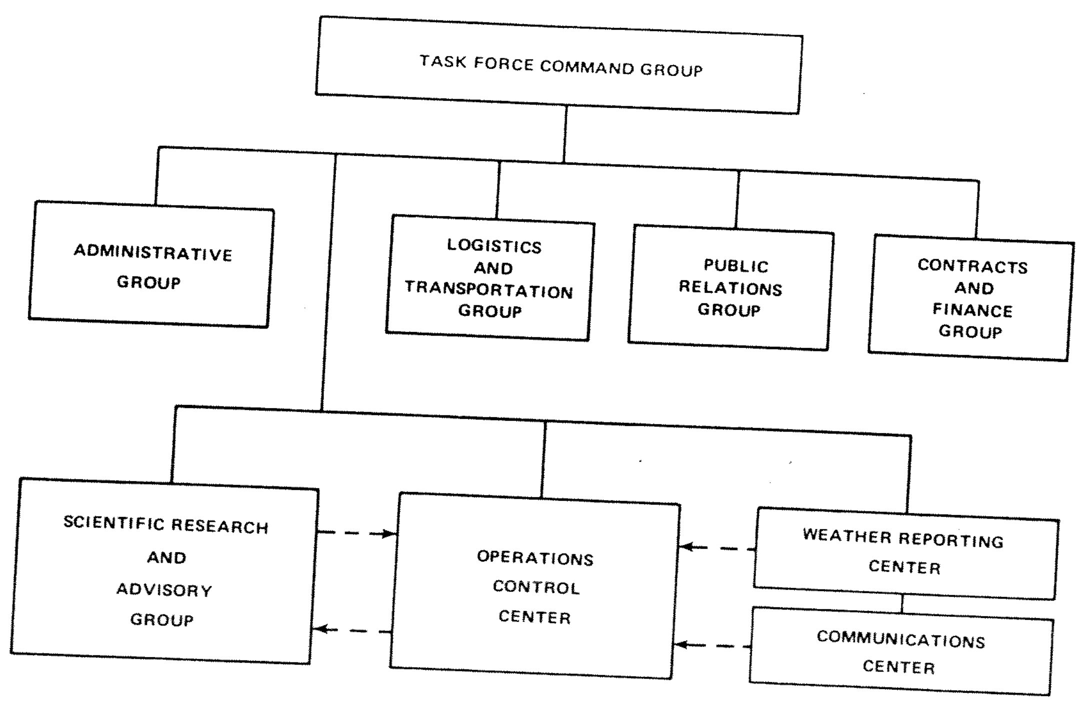
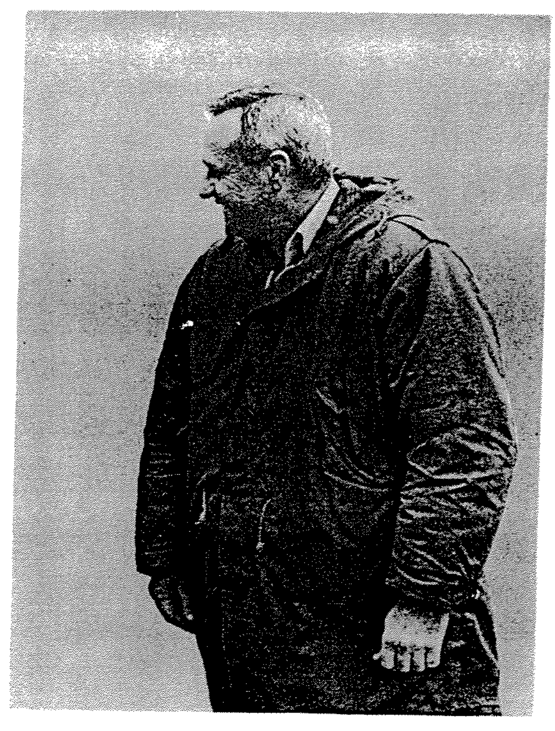


Figure 11. Task Force Headquarters.

Base, CFB Gagetown in New Brunswick. Participating units included 2 Field Squadron, 1 Battalion, Black Watch and Royal Canadian Dragoons. The 450 Squadron Voyageurs provided helicopter support. The military units concentrated initially on the construction and installation of booms to contain the oil, switching later to beach clearance where they worked in close co-operation with civilian personnel.

Captain Sven A. Madsen
Esso International Oil Company



Captain Robert Belsher
Murphy Pacific Marine Salvage Company

Figure 12. Leaders of the Salvage Force.

INITIAL PREPARATIONS, 1 – 11 March

Preparations for the salvage effort to debunker the ARROW were well underway by the end of February. The lighter had been chartered. The CURB was enroute from New York with its experienced salvage gang, its beach gear, and other vitally needed salvage equipment. RCN divers had completed tests and experiments in Halifax with equipment for penetrating the ARROW's tanks and attaching valves and fittings for hose connections. Equipment for pumping, such as pumps, hoses, boilers, and generators, had been located for the most part and was either at Mulgrave or enroute.

With the arrival of the CURB in the operational area on 2 March, preparations intensified. The YMT-12 began tapping the ARROW's tanks at the salvage site. The CURB prepared the moor for the barge, IRVING WHALE, immediately upon its arrival at Mulgrave and layed the four legs of the moor during the first week, making two deployments to the Cerberus Rock area for this purpose. Concurrently, work went forward at Mulgrave to outfit the barge for salvage operations. Personnel from both the CURB and the Port Hawkesbury Shipyard participated in the latter task.

The nucleus of a pumping capability was assembled first. This consisted of one steam boiler and sufficient cargo hoses and steam traces to man two pumping stations. Other equipment, including a second boiler and the necessary cargo hoses for four additional pumping stations, was expected shortly. The salvage master decided to initiate debunkering operations with just the partial pumping capability, anticipating that the remaining equipment could be delivered to the salvage site to complete the remainder of the outfitting.

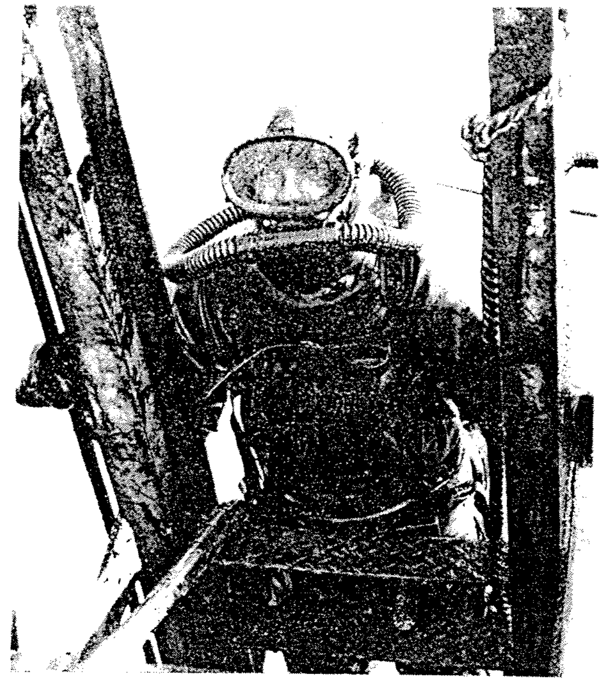
YMT-12's divers succeeded in penetrating two tanks and fitting them with hose attachments by 11 March, working in 28°F water temperatures, erratic seas and highly adverse weather (figure 13). The working conditions encountered by the divers in these preparatory tasks revealed clearly the nature of the job that lay ahead of the deploying salvage force.

FIRST DEPLOYMENT, 13–16 March

The CURB sailed for Cerberus Rock on the morning of 12 March with the IRVING WHALE towed alongside, a trip of about 3 hours. The CURB put the barge into the four-point moor that afternoon, a task requiring exceptional seamanship on the part of the CURB's captain.

It took the better part of the next day for the YMT-12's divers to connect the first cargo hose. This was an 8-inch hose rig with a closed-loop steam trace. This rig was connected to tank 8C, the first target of oil recovery operations. The steam pump was turned on at 1730.

Figure 13. Canadian Navy Divers Returning from the ARROW.



Although bad weather forced disconnection of the cargo hose at 2030, the flow of Bunker "C" into the tanks of the IRVING WHALE in these first few hours of pumping was tremendously significant to the salvage force. A rate of about 40 barrels per hour at a discharge temperature of 117°F was achieved. It was enough to demonstrate that the debunkering technique was workable.

Pumping did not resume until the following evening when the weather abated sufficiently to permit the divers to retrieve the cargo hose. The CURB proceeded to fabricate another steam trace in preparation for hooking up a cargo hose to tank 8P and putting a second pumping station in operation. The CURB also topped off the barge with feed water and, on the following day, with fuel for the temporary boiler and for the barge's generators. The salvage force injected steam into tank 8C through a second spool piece in an effort to heat the sluggish oil and increase the pumping rate.

Foul weather developed again on 16 March. Pumping operations had to be discontinued at 1500, although an underwater TV survey of the wreck was completed earlier in the day before the weather worsened. During the night, gale force winds and waves of up to 15 feet battered the barge, finally blowing it out of the moor and leaving it, the next morning, secured with only one of the original four mooring lines.

Since the storm had coincided with the arrival of the remaining equipment, the salvage master decided that the CURB should take the barge back into Mulgrave where outfitting could be completed and the barge could be prepared for a stronger and more permanent moor.

The salvage force, accordingly, returned to Mulgrave on 17 March having recovered 2610 barrels of Bunker "C" in 32 hours of pumping and with the expectation that debunkering could proceed faster on the next deployment.

Table 1. Barrels of Bunker "C" Recovered During First Deployment, 13-16 March.

DATE	TANKS PUMPED	DAILY TOTAL	CUMULATIVE TOTAL
13 March	8C	200	200
14 March	8C	480	680
15 March	8C	1430	2110
16 March	8C	500	2610

REFITTING AND COMPLETION OF PREPARATIONS, 18–21 March

During this period, the Royal Canadian Navy installed a second power plant aboard the barge. The Port Hawkesbury Shipyard also delivered four 6-inch cargo hose rigs with open steam traces. Installation of the RCN steam generator and the arrival of these hose rigs enabled the salvage force to develop a multiple-station pumping capability. Repair work was also performed on the first or portable boiler that had been used during the first pumping deployment.

The CURB took advantage of this brief period in port to prepare heavier mooring lines for the barge and to arrange for laying a fifth leg for the moor. Its salvage gang was also heavily engaged in the work of completing the barge's outfitting.

The YMT-12 had found its berth at Arichat jetty completely untenable during the southwesterly gales. Accordingly, on 18 March, it anchored in the lee of Jersyman Island, near Arichat, using one of the concrete clump mooring anchors that had been installed at the wreck prior to the CURB's arrival.

YMT-12 divers destroyed the ARROW's funnel with explosives on 19-20 March to ensure that it would not obstruct the IRVING WHALE. The funnel was severed in sections using a series of explosive cutting charges. Each charge was kept as small as possible to minimize risk of damage to the tanks. These efforts provided a clearance of about 12 feet over the superstructure and left a hole with a mean diameter of 20 feet. The divers also continued their work of penetrating the ARROW's tanks and installing fittings for the hoses.

SECOND DEPLOYMENT, 22 March – 2 April

The salvage force returned to Cerberus Rock late on 22 March, resumed pumping the next afternoon, and immediately encountered an ice storm. Hoses had to be slipped overboard and communications between the CURB and IRVING WHALE were lost temporarily. However, a second effort was begun the following day and by 25 March four pumping stations were in operation.

At this time divers were attempting to install fittings on the ARROW's bunker. They requested and received permission to use C-4 explosives to remove an obstruction that was hampering their efforts. Detonation of a 4 1/2-pound charge jarred loose a toggle bolt securing the tank top cover. The cover blew open, releasing about 300 tons of fuel oil that rose to the surface and dispersed, flowing from the bunker for about 4 hours.

Task force headquarters, ashore, placed its contingency plan for oil spills into effect as efforts were made to observe the oil slicks and predict their paths. Fortunately, the oil was carried seaward and did not further threaten the shores of Chedabucto Bay. The emergency caused by the accidental release of the ARROW's fuel was terminated on 26 March.

Pumping continued, primarily from three tanks, 8C, 9C, and 8P, in spite of boiler breakdown and generator problems. The pumping rate by now had reached 250,000 gallons per day using three suction hoses. The salvage force looked forward to increasing this daily rate to as much as 420,000 gallons using all facilities. Since the capacity of the barge was limited to about a million gallons (30,000 barrels), arrangements were initiated to have a lighter come alongside to receive the recovered oil.

The salvage master reported tank 8C clear of oil on 27 March. This was the first tank to be discharged. To ensure that no oil remained in the tank, either through cavitation or for other reasons, it was decided to pump this tank several times during the ensuing 24-hour period. This was done until no oil was visible in the discharge from the pump. This procedure was followed on every tank pumped during the debunkering operation.

The feed water problem became severe by 28 March as sustained pumping continued from multiple pumping stations and the total amount of Bunker "C" recovered rose past the 12,000-barrel mark. Delivery of 150,000 gallons of feed water by the ARCTIC SHORE, on oil rig tug, alleviated this problem. The two steam power plants supporting the pumping system aboard the barge had by now reached a consumption rate of 5,000 gallons of feed water per day.

The general status of salvage operations on 28 March was:

Pumping had been completed on tank 8C.

Pumping was nearing completion on tanks 8P and 9C.

Pumping would start next on tanks 7C and 7S. An airlift was being prepared for use on tank 7C.

Tanks 7P, 8S, and 6S, in that order, remained to be tapped. Tank 8S had to be retapped as penetration had not been achieved with the original tap.

The salvage master, working from his original estimate of the amount of oil in each cargo tank, was proceeding on the assumption that the cargo tanks were about half full. Having recovered 6500 barrels from tank 8C, he calculated that a maximum of 30,000 barrels remained in the other tanks.

Major problems were encountered with the two steam power plants as well as their supporting generators during the next few days, reducing the overall discharge rate. However, the salvage force managed to keep two pumps in operation. The amount of cargo recovered rose past the 16,000-barrel mark as March drew to a close. Plans were being made to transfer the oil from the lighter to the coastal tanker IMPERIAL CORNWALL. The salvage force was working an average of 16 hours per day per man in this period.

In spite of the maintenance problems with the boilers and generators, the salvage force had succeeded in putting four pumping stations on line by 1 April and brought the discharge total well past the 20,000-barrel mark. The next day, with heavy weather expected, both boilers again in need of repair, and the barge's cargo tanks nearly full of recovered Bunker "C," the salvage master decided to break off pumping operations. The IRVING WHALE slipped all cargo hoses and was removed from the mooring. The salvage force then headed for port.

Table 2. Barrels of Bunker "C" Recovered During Second Deployment, 23 March – 2 April.

DATE	TANKS PUMPED	DAILY TOTAL	CUMULATIVE TOTAL
23 March	8C	200	2,810*
24 March	8P,8C,9C	1,190	4,000
25 March	,8P,8C,9C	2,500	6,500
26 March	8P,8C,9C	5,000	11,500
27 March	8P,8C,9C	800	12,300
28 March	8P,9C	1,400	13,700
29 March	7S,9C	800	14,500
30 March	7S,9C	1,600	16,100
31 March	7C,7S,9C	1,500	17,600
1 April	7P,7C,7S,9C	3,400	21,000
2 April	7P,7C,7S,9C	2,304	23,304

* Includes 2,610 barrels recovered during first deployment

The salvage force returned to Mulgrave with an estimated 23,304 barrels (815,641 imperial gallons) of Bunker "C" aboard the IRVING WHALE and the end of the debunkering effort clearly in sight. Offloading to the IMPERIAL CORNWALL was completed on 3 April.

THIRD DEPLOYMENT, 5–11 April

After offloading the Bunker "C," the salvage force remained in Mulgrave a few days, repairing the boilers, refueling the barge, and topping it off with feed water. HMCS CAPE SCOTT did repair work on the YMT-12 at Port Hastings, the diving tender then returning to Arichat. Heavy weather kept the force in port until 5 April. The salvage master estimated that five more pumping days might be needed to complete the salvage effort.

The CURB, with the barge in tow, left Mulgrave for the salvage site on 5 April. It moored in Inhabitants Bay that evening as it was too windy to undertake salvage operations. Mooring was completed, hoses reconnected, and pumping underway by late the following day, 6 April. The pumping effort concentrated first on finishing tank 9C and the port starboard wing tanks in the #7 cargo compartment.

The following day divers from YMT-12 reported that the bow section of the ARROW was completely free of Bunker "C." They had physically swum through the ship's forward cargo tanks. This report was the first confirmation that no cargo remained in the forward wing tanks on the port side. The hull had continued to disintegrate and all the forward tanks were now open to the sea.

The salvage force had recovered an additional 6000 barrels by the evening of 8 April when the RCN steam generator failed. Pumping had been completed from tank 9C and was in progress on all three tanks in the #7 cargo compartment. Tank 6S had been tapped and rigged for pumping and divers were preparing to check the settling tanks in the after portion of the wreck for possible oil. The problem with the RCN steam generator appeared to be in the feed water modulator valve system.

Pumping proceeded, nevertheless, in the next few days, with principal reliance being placed on the "old" or portable boiler to finish the job. Divers confirmed that the ship's settling tanks were clear. By 10 April, all tanks had pumped clean water except tanks 6S, 7S, and 8S. Although the latter tank had been thought to be empty, subsequent checking revealed a recurrent buildup of oil. It appeared that oil from tank 7S was seeping into tank 8S and that the latter would continue to buildup until the former was empty. This proved to be the case; they had, in effect, become one common tank.

With pumping obviously nearing completion and over 10,000 barrels of Bunker "C" safely recovered during this third and final deployment, wind-up preparations began. Divers retrieved 10 of the 13 gate valves that had been installed on the ARROW's deck and blanked off the spool pieces. Three hose rigs were also recovered.

On 11 April, 66 days after the ARROW had smashed into Cerberus Rock, the salvage force retrieved the last few barrels of oil. Tanks 6S, 7S, and 8S were all pumping water by 1330 with no evidence of any remaining oil. These three tanks were blanked off during the afternoon and the remaining three cargo hoses were brought back aboard the barge. The CURB proceeded to break the moor and returned to Mulgrave with the IRVING WHALE in tow, arriving in port late in the evening. The salvage force had recovered 13,620 barrels of Bunker "C" during the third deployment, making a grand total of 36,924 barrels salvaged from the wreck of the ARROW.

The CURB returned to the salvage site a few days later to recover its beach gear. Operations to retrieve the moor legs were interrupted by foul weather and rough seas.

The CURB departed Mulgrave on 15 April with the IRVING WHALE in tow. It proceeded to Halifax Harbor where the lighter was turned over to Imperial Oil Company authorities. The CURB then returned to its home port of New York, another salvage job completed. The YMT-12, after staging a diving display for the people of Arichat, was also detached. It left the operational area on 14 April, made an uneventful passage overnight to Halifax Harbor, and secured at the Fleet Diving Unit in Dartmouth early on 15 April.

Table 3. Barrels of Bunker "C" Recovered During Third Deployment, 6-11 April.

DATE	TANKS PUMPED	DAILY TOTAL	CUMULATIVE TOTAL
6 April	7P,7S,9C	1,400	24,704*
7April	7P,7C,7S 8S,9C	3,125	27,829
8 April	7C,7S,8S 9C	3,575	31,404
9 April	6S,7C,7S 8S	2,714	34,118
10 April	6S,7S,8S	2,123	36,241
11 April	6S,7S,8S	683	36,924**

* Includes 23,304 barrels recovered during first deployments

** This total includes both oil and oil/water emulsion. The Imperial Oil Company undertook the task of separating the oil after the operation. It was estimated that as much as 28,000 barrels of Bunker "C" could be reconstituted and used for commercial purposes.

CONDUCT OF CONTAINMENT AND CLEANUP OPERATIONS

TACTICS FOR CONTAINING THE OIL

A variety of measures was used for dealing with the oil in the water. The principal method was the use of floating booms to enclose inlets and coves where the oil had approached the beaches, trapping it so that it could not be blown back out to sea to foul other areas later. Army engineers determined that fir trees could absorb more than three times their own weight in Bunker "C" and, accordingly, most of the booms were lined with foliage of this type. Booms were also thrown across harbor entrances, fish plants, and other critical areas to deny access to the oil. The Imperial Oil Company procured the first set of booms to be used, at a reported cost of approximately $140,000. As the operation progressed, Army engineers took over the job of boom fabrication and placement.

The task force made an early decision not to use dispersants or detergents within 5 miles of shore for fear of toxic reaction to marine life. For similar reasons, it was decided that oil would not be sunk within the bay area. The use of COREXIT, a surfactant that breaks up the oil into tiny particles and allows it to disperse, was attempted briefly before biologists objected to its possible toxicity.

Burning was considered the most effective technique for attacking the oil in the water. Flame throwers discharged napalm into straw-covered oil in an effort to ignite it. They proved to be ineffective and were withdrawn. Two commercial products were used on a small scale. The first was Corning SEABEADS, manufactured by the Pittsburgh Corning Glass Company. They are small pumice-like glass beads that had proved effective in other oil spills by acting as a wick for the oil. The second was KONTAX, a German product that was the only known commercial product allegedly capable of firing fresh Bunker "C." Both of these burning agents are very expensive. Only very limited results were achieved.

The basic limitation in the use of materials such as COREXIT, Corning SEABEADS, or KONTAX is time. Unless the floating oil can be treated quickly, it loses its vulnerability to substances such as these. Bunker "C" that has been in the water over 25 hours will have absorbed large quantities of water (possibly up to 50 percent). The effectiveness of dispersants, detergents, and burning agents declines markedly as water is absorbed.

CLEANUP PROCEDURES

Beach cleaning methods were primarily mechanical. The basic tactic was to clean selected beaches between the high and low water mark in order to prevent the tides from lifting oil from one beach and carrying it to another. Beaches in and around Arichat received first priority for the deployment of heavy equipment belonging to eight contracting firms in the bay area. The oil must be attacked as quickly as possible. The longer it remains on the beach the greater is the earth moving operation required since some of the oil sinks into the sand. Aging and weathering also make the removal process more difficult.

Absorbents were used to accelerate the cleanup work. Canadian scientists had determined in laboratory experiments that peat moss would absorb up to eight times its own weight of floating Bunker "C." It was also an effective absorbent ashore. Large quantities of peat moss were mixed with the oil on the beaches to prepare it for movement by heavy equipment.

A mechanical device that attracted much attention during cleanup operations was the SLICK LICKER. Developed by scientists of the Canadian Defense Research Establishment Pacific, this is a conveyor belt apparatus that laps up oil trapped in inlets and near the beach. Mounted in a craft, such as an LCM, the device transfers the scooped up oil to 55-gallon drums for subsequent disposal. Despite the availability of heavy equipment, much of the oil was accessible only to rakes and shovels, requiring hard and tedious manual labor (figure 14).

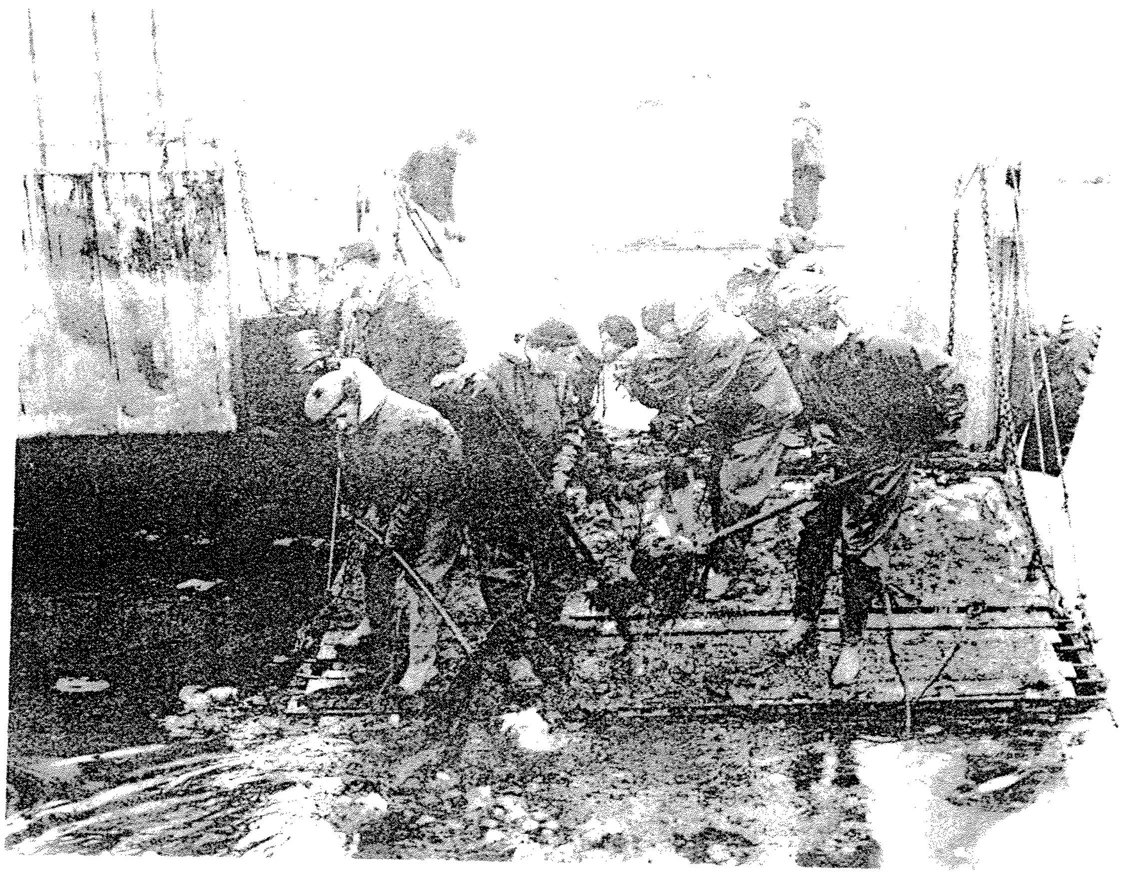


Figure 14. Canadian Army Troops and Heavy Equipment Attacking the Stubborn Bunker "C" on Janvrin Island.

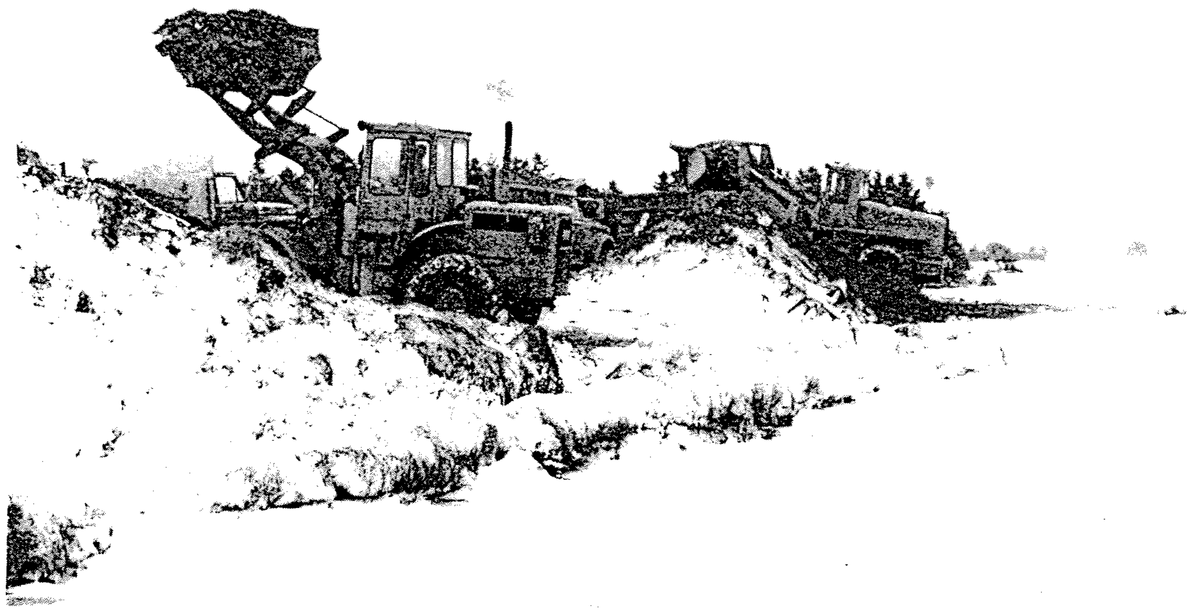


Figure 14 (cont'd). Canadian Army Troops and Heavy Equipment Attacking the Stubborn Bunker "C" on Janvrin Island.

Dispostion of the oil removed from the beaches required a careful selection of disposal sites. Dry quarries were suggested but ruled out because, being dry, they would necessarily have porous bottoms through which the oil would eventually escape to contaminate fresh water beneath the surface. Clay-based areas were selected since clay is impervious to Bunker "C."

CONTINGENCY PLANNING

The task force recognized the twin risks of either the wreck breaking up under the action of sea and swell or an accidental, uncontrolled oil spill during the conduct of salvage operations. Accordingly, much staff effort went into the development of a contingency plan aimed at preventing further contamination of the shorelines, harbors, and fishing grounds.

The plan was designed to produce an automatic and immediate reaction by all elements of the task force. Warning and detection measures were a key feature of the plan since the staff estimated that oil escaping from a breakup of the wreck or from an accidental massive spill would reach the shores of Isle Madame within 4 hours. The plan provided for procedures to contain the oil at the wreck site, if possible, or to attack it on the water and beaches depending on the conditions of the spill. The contingency plan was partially implemented on 25–26 March when oil did escape accidentally from the wreck.

VESSELS PARTICIPATING IN THE SALVAGE EFFORT

PRINCIPAL VESSELS

The recovery of oil from the tanker ARROW required the sustained participation of three principal vessels:

MV CURB, a U. S. Navy salvage ship operated by the Merritt Division of Murphy Pacific Marine Salvage Company.

IRVING WHALE, an oil transfer barge belonging to the Irving Oil Company.

YMT-12, a diving tender of the Royal Canadian Navy.

THE MOTOR VESSEL (MV) CURB

Background

As it became increasingly evident that the scope and complexity of debunkering operations would require the marshaling of additional salvage resources, discussions were conducted between task force planners and representatives of the Supervisor of Salvage, U. S. Navy, concerning possible use of the Motor Vessel (MV) CURB. This vessel, located in New York City, offered a unique combination of salvage support capabilities. Both the range of its equipment and the experience of its salvage gang would provide indispensable assets for undertaking the oil recovery effort.

The CURB (figure 15) was designed and constructed as a U. S. Navy Salvage Ship (ARS) in 1943. Although still owned by the U. S. Navy, it is today on a long-term lease under bareboat charter to the Murphy Pacific Marine Salvage Company of Emeryville, California. It is manned and operated by personnel of the Merritt Division of Murphy Pacific, based in New York City. Under conditions of the long-term lease, the Navy retains forst call on the CURB's services. The Supervisor of Salvage made CURB available for the operation.

Description

The CURB is 213 feet long and weighs 1202 gross tons. It normally carries a crew of 30 to 35 men, including the salvage force, although it can accommodate 49 persons. It has a 10,000-mile steaming range. The trip from New York to the operational area was made in 68 hours at a cruising speed of 11½ knots.

The CURB's equipment includes a complete salvage workshop, a machine shop, diving locker, automatic towing engine, pumps, compressors, and eight 4-ton Eells anchors. Capable of functioning as a towing vessel as well as a salvage tender, the CURB has the necessary spaces

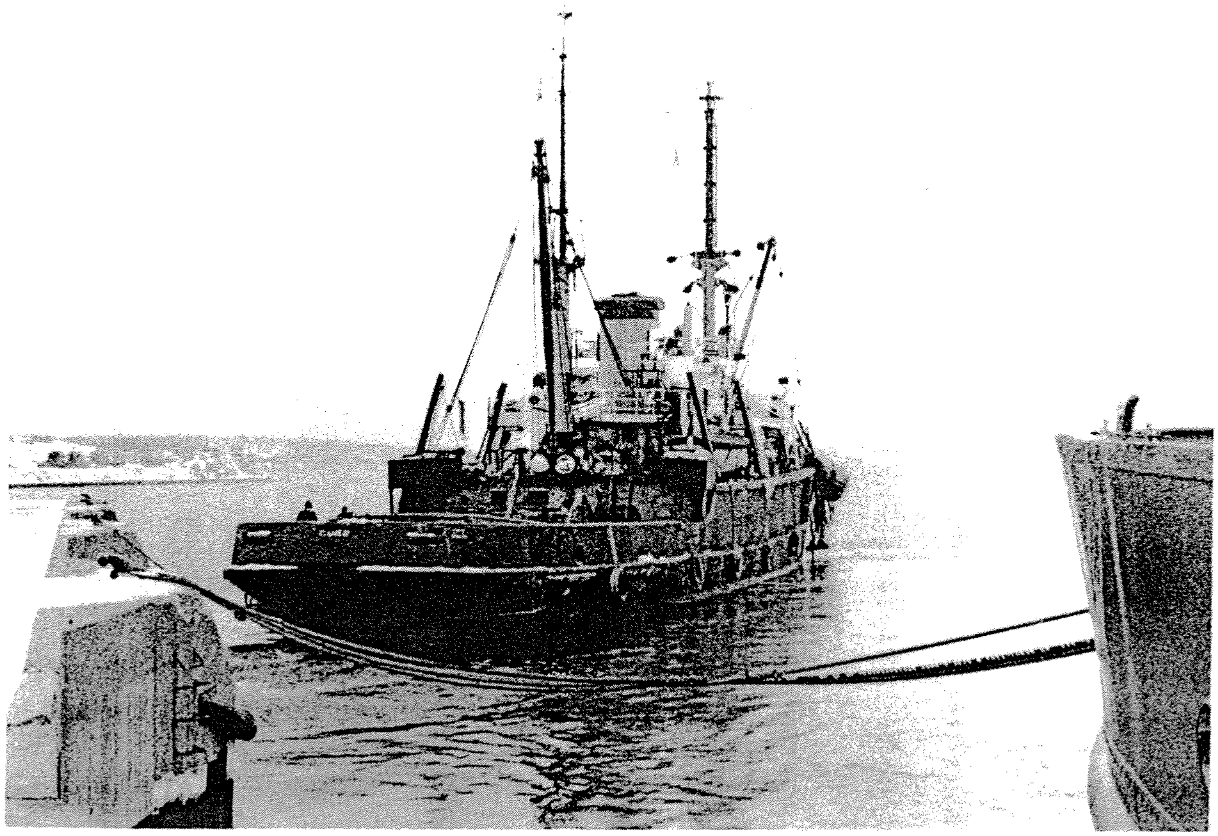


Figure 15. MV CURB, Salvage Tender and Command Ship Provided by the Supervisor of Salvage, U.S. Navy.

and communications equipment to provide headquarters facilities afloat for on-site command of salvage operations. Its communications equipment includes a single sideband capability for ship-to-shore communications.

The Murphy Pacific Marine Salvage Company is also capable of outfitting the CURB for extensive diving services, including the provision of a decompression chamber. The CURB was not outfitted for this function on the ARROW salvage operation, however, because of the availability of Canadian diving resources.

The Role of the CURB

The major contributions of the CURB in the salvage effort were the provisions of:

1. Beach gear with personnel and equipment for preparing and laying the four-point moor for the barge, IRVING WHALE.

2. Towing capability for transporting the barge to and from the salvage site and for placing it in the moor.

3. Personnel and equipment to prepare hose rigs, pumps, and related equipment for the pumping system aboard the barge.

4. Personnel for the salvage gang aboard the barge.

5. Afloat facilities for command of oil recovery operations at the salvage site.

In addition to performing all the above functions, the CURB's role as a command facility afloat was equally significant, since it enabled the salvage force to conduct extended operations at the site of the wreck.

THE DIVING TENDER, YMT-12

The YMT-12 (figure 16) is a 90-foot long Royal Canadian Navy (RCN) diving tender. It normally operates out of Dartmouth in the Halifax Harbor complex where it supports Fleet Diving Unit (Atlantic) and training operations of the RCN Divers' School. It arrived in the operational area on 28 February and its divers began the critical task of penetrating the ARROW's cargo tanks on 2 March. Prior to that time, RCN divers from the Fleet Diving Unit had already been in the area assisting in early efforts to ignite and burn the spilled Bunker "C," and later, conducting surveys of the wreck to ascertain its condition.

The YMT-12's sea-keeping capabilities are relatively limited. This restricted the capability for all weather diving in the Cerberus Rock area, which is in an open roadstead completely exposed to the vagaries of winter weather conditions. The YMT-12 used the barge or the CURB as a lee at the salvage site, normally taking up a three-point moor for diving operations. Fortunately, Arichat was only a few miles from the wreck site, as was Janvrin Island. The YMT-12 withdrew to one of these havens each evening following diving operations and returned to the salvage site at first light each day that weather permitted.

The YMT-12 supported 12 divers during the operation and also provided medical support for the salvage force afloat. The RCN divers from the YMT-12 participated in all phases of the salvage operation. They mastered the hot tap method of penetrating the ARROW's cargo tanks, concentrating their main efforts on the difficult underwater work of attaching spool pieces and gate valves, tapping the tanks, and attaching and maintaining the cargo hoses. Other diving work included conducting surveys, assisting with mooring the barge, and applying explosives to remove underwater obstructions.

Despite the interruptions forced by the periodic winter storms and gales, the YMT-12 conducted diving operations on 27 days between 2 March and the conclusion of pumping operations on 11 April. It also served briefly as a command ship for the execution of contingency operations in reaction to the accidental oil spill from the ARROW's bunker tank on 25 March. Canadian naval divers, in most instances, are required to work in cold water and cold weather, frequently in exposed locations. This experience contributed greatly to their ability to conduct extended diving operations in support of the salvage effort.

The heavy, adhesive, black cargo oil was, in many ways, a greater adversary then the cold and erratic weather. Divers had to contend frequently with fouling of diving suits and equipment. Visibility, however, did not appear to be a major problem. It exceeded 20 feet at the start of the operation. Subsequently, the increased activity around the wreck site periodically reduced it to 5 or 6 feet. On clear, calm days it was possible to discern the outlines of the wreck from the surface.

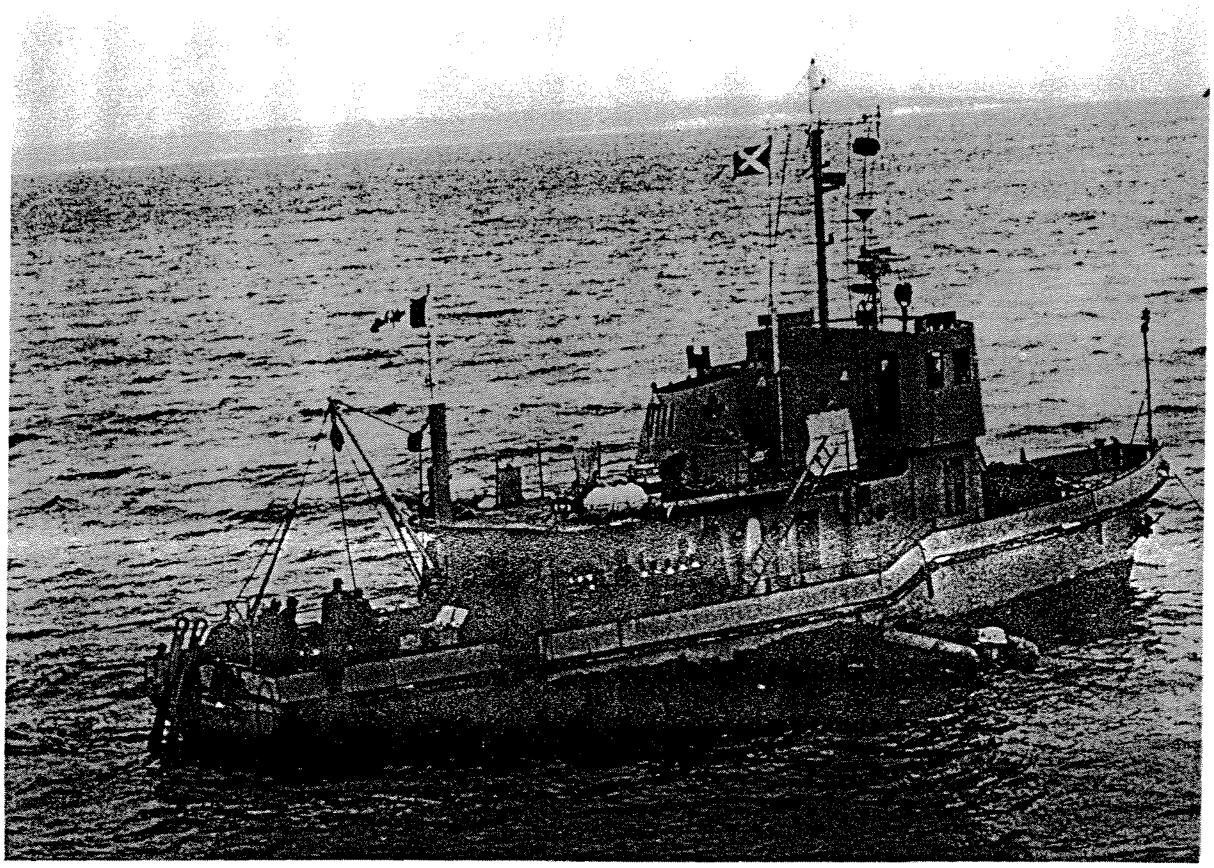


Figure 16. YMT-12, Diving Tender of the Royal Canadian Navy.

THE OIL TRANSFER BARGE, IRVING WHALE

The task force chartered the oil transfer barge, IRVING WHALE (figure 17), from the Irving Oil Company to serve both as a salvage pumping platform and as a receptacle for the retrieved oil. This barge was an obvious choice to perform these lighterage functions. It was immediately available in the operational area. It also had certain basic characteristics and equipment that could be exploited in the oil recovery effort, although much work would be needed to outfit it properly for pumping operations.

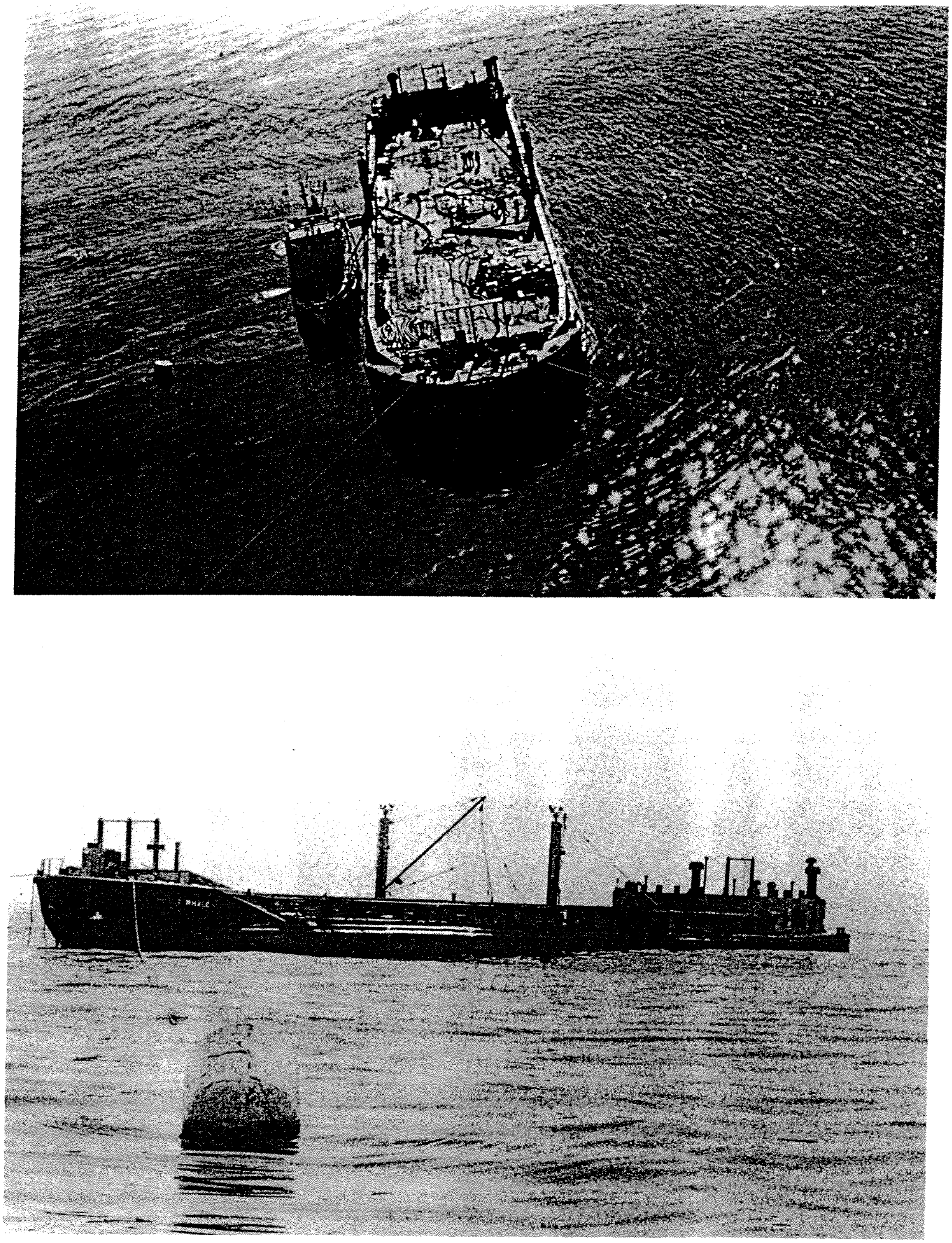


Figure 17. Views of the Oil Transfer Barge, IRVING WHALE.

Capabilities of the Barge

The cargo capacity of the IRVING WHALE was substantial. It could carry about 30,000 barrels of Bunker "C" at 170°F. This was important since the estimated amount of oil remaining in the tanks of the ARROW was between 30,000 and 50,000 barrels. It meant that operations would not have to be interrupted excessively to transfer the recovered oil to other vessels. There were no facilities ashore in the Chedabucto Bay area to receive oil. Beach discharge would have required a trip, towing the barge, to Halifax about 150 miles away. Additionally, it was not easy to obtain other lighters for repeated cargo transfer operations. As it turned out, only one transfer was required. About 15,000 barrels of oil were transferred to the small coastal tanker, IMPERIAL CORNWALL, on 3 April. The remaining oil, almost 22,000 barrels, was discharged at Halifax at the conclusion of the operation.

In conjunction with its carrying capacity, the barge's capability for heating its cargo oil was also important. It used a heating system that included a series of tubular coils in the cargo tanks. A hot solution, Monsanto Fluid, pumped through these coils, was capable of heating the barge's cargo as high as 200°F. In addition to fulfilling the basic requirement of keeping the recovered oil at the proper temperature for further transfer and disposition, this heating system also provided a possible means of furnishing heated oil from the barge to mix with and heat the Bunker "C" in the ARROW's tanks. This method of heating the ARROW's cargo was given extensive consideration early in the operation.

The IRVING WHALE had been designed for oil transfer operations in northern ports. This was its normal function. The exceptional rise and fall of the tides in this area require that cargo transfer operations be conducted very rapidly. The barge was equipped with high performance pumps manufactured by Stoddard and Pitts, Incorporated. It was a matter of only a few hours for the IRVING WHALE to discharge the recovered Bunker "C" to the IMPERIAL CORNWALL using these pumps.

The size and design of the barge made it well suited for use as a salvage pumping platform. It was 265 feet long and had a beam of 65 feet. The wide beam and its flat bottom made it extremely stable. It had excellent sea-keeping qualities once installed in its four-point moor. It was comparatively easy to walk and work on the deck, even in 50-knot winds and swells of 6 and 8 feet. The extensive deck area provided adequate work space to install and operate the salvage pumps and their supporting equipment, such as boilers, generators, and hoses.

The barge was also equipped with hydraulic booms amidships that could be used to maneuver the heavy hose rigs needed for pumping and for general purpose work in support of the operation. It also had a newly installed 225 KW diesel electric generating set as well as tank facilities for the supply of fuel oil and feed water. These were important resources that could be exploited in developing a pumping system.

Limitations of the Barge

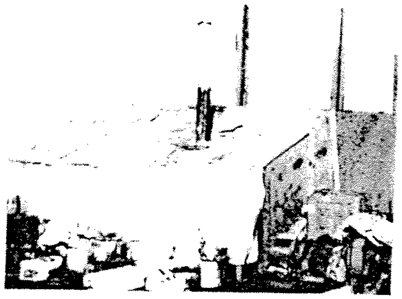
The IRVING WHALE was not self-propelled. Nor had it been designed for mooring and unmooring in the open sea. These limitations, coupled with its great size, made mooring operations difficult. A mooring winch had to be installed and the necessary mooring lines, legs and anchors provided. Apart from mooring, however, the fact that the barge was not self-propelled did not seriously limit its use. The CURB could tow it easily and there were drill rig tenders available to help maneuver it in and out of port at Mulgrave when required.

The basic limitation of the barge stemmed from the fact that it had not been designed as a salvage lighter. Much of its equipment could not be used or adapted to directly support the salvage effort. Its high capacity pumps, for example, were centrifugal pumps intended to move fuels at high temperature and low viscosity. They were not suitable for pumping the highly viscous Bunker "C" from the wreck. Neither could its cargo heating system be used to provide steam as it used a fluid other than water. The barge also lacked the living facilities that could accomodate a fully organized salvage force conducting extended operations. All these factors meant that a major outfitting effort would be necessary to provide the IRVING WHALE with the equipment and facilities needed for the salvage attempt.

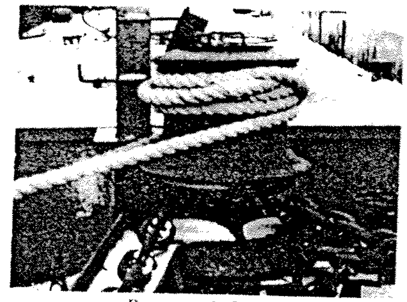
Outfitting the Barge

The outfitting effort transformed the barge into a tender capable of conducting extended salvage operations. Two steam power plants were installed on the main deck, one forward and one aft, to support the pumping effort. Pumping stations were set up amidships. An air compressor was brought aboard to provide an airlift capability. A mooring winch was placed in the forward deck area. Feed water tanks were positioned near each steam power plant and the necessary fuel service tanks were also installed. The fully outfitted barge is shown in figure 18.

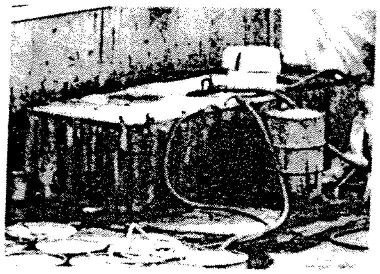
The barge, itself, had only one "crew member." He was a maintenance man who looked after the barge's 225 KW generator and its organic pumping system. The remainder of the salvage force was provided principally by the CURB and by the Royal Canadian Navy. The CURB provided a rotating salvage force of five men to operate the pumping system on a 24-hour basis. The CURB's salvage force operated all aspects of the system except the two steam generators, which were normally tended by three RCN operators and two civilian boiler tenders who were rotated from shore facilities at Arichat. Both RCN and civilian technicians



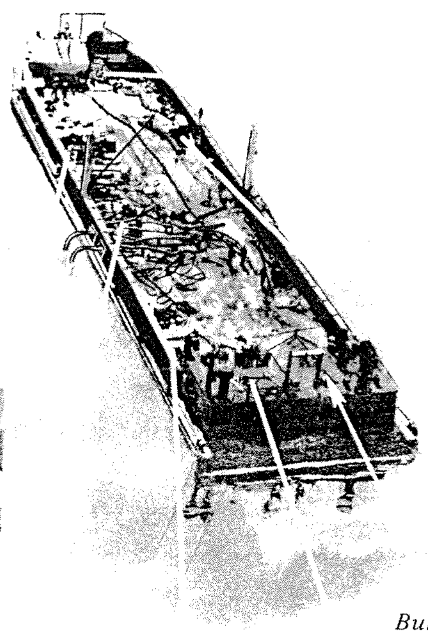
Portable Boiler in Shack

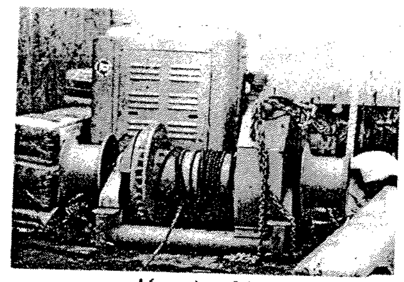


Powered Capstan



Primary Feed Water Tank



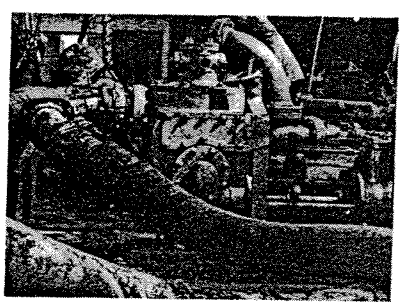


Mooring Winch

Mulching Machine and Peat Moss for Oil Spill Contingencies

Air Compressor for Airlift

Bunkhouse



Pumping Stations Amidships

Fuel Tanks For RCN Steam Generator

RCN Steam Generator and 30 KW Generator in Shack. Fuel Tank for 30 KW Generator and Secondary Feed Water Tank in Front of Shack.

Figure 18. Barge, IRVING WHALE, Outfitted for Salvage Operations.

were brought aboard the barge periodically for repair jobs beyond the capabilities of the on-board force. The severe weather conditions and the periodic need to keep the force for long periods of time prompted construction of a heated bunkhouse on the main deck of the barge in its after section. The shelter became especially valuable on several occasions when high winds and heavy seas prevented relief of the crew for periods in excess of 24 hours.

In addition to its salvage role, the IRVING WHALE had a secondary mission of providing facilities and equipment for oil containment in the event of accidental oil spills from the wreck. Equipment put aboard the barge for this purpose included a portable oil spill boom for containing the oil and a mulching machine to be used for spreading peat moss throughout the oil spill. Large quantities of peat moss were stored on the barge's deck for these contingencies. A powered, inflatable rubber raft was also made available for use in positioning the boom and spreading the peat moss.

OTHER SUPPORT VESSELS

Other vessels that supported the salvage effort intermittently included the following:

CCGS NARWAHL, a Coast Guard cutter under operational control of the Canadian Department of Transport. This vessel saw extensive service throughout the operation. Based at Canso Lock near Port Hasting, it provided living accommodations for the participating military personnel. It was also used for several logistic support missions to the salvage site.

HMCS CAPE SCOTT, an RCN vessel (ARG type). This ship provided technicians and facilities for maintenance of equipment and repair work aboard the barge and the diving tender. It relieved the NARWAHL late in the operation.

IMPERIAL CORNWALL, a small coastal tanker belonging to the Imperial Oil Company. The IRVING WHALE offloaded a major portion of its recovered Bunker "C" to this vessel midway during the operation. Use of this tanker as a lighter to recover the oil from the bow section of the ARROW was also considered.

ARCTIC SHORE, an oil rig tug under contract to the Shell Oil Company. This ship was used to top off the barge with feed water. It also helped to maneuver the barge in the harbor at Mulgrave.

CCGS SIR WILLIAM ALEXANDER, CCGS RALLY, CCGS RAPID, Coast Guard vessels. These ships were used early in the operation as diving tenders prior to the arrival of the YMT-12.

MOORING THE IRVING WHALE

FACTORS IN PREPARING THE MOOR

The stern section of the ARROW was lying on a 230° heading at a depth of 90 feet. Having established that the bulk of the remaining oil was in this section, the salvage master decided to attack it first, leaving the bow section for later consideration. Salvage planners determined that the IRVING WHALE should be positioned in a four-point moor directly over the center of the stern section and perpendicular to it. The position of the barge and details of the moor are shown in figure 19.

Placing the barge in this position would equalize the distances between the various pumping stations aboard the barge and the cargo tanks of the ARROW, thus providing maximum flexibility for shifting the suction hoses. The perpendicular orientation also avoided the ARROW's deck house and funnel. The funnel was awash and there were 13 to 18 feet of water above the deck house depending on the height of the tide. Centering the barge would leave only 55 feet between it and the funnel.

Consideration of three principal factors led quickly to the determination that a four-point moor would be the best possible technique for positioning the barge. First, the barge had to be in a highly stable position to minimize tensions on the suction hoses. Secondly, extended salvage operations of four to five weeks and possibly longer duration were anticipated. Thirdly, the salvage site was in open water where a four-point moor would be the minimum required to hold the heavy barge in place. The winter weather and high winds normally experienced from several directions made a strong moor essential.

The barge itself had not been designed with the idea that it might be moored for extended periods for pumping operations in the open sea. It did have a powered capstan on the bow that could be used for controlling mooring lines. However, this capstan was not adequate to handle all the lines that would be necessary for a four-point moor. Arrangements were made, therefore, to obtain a mooring winch from the Murphy Pacific Marine Salvage Company. The winch was transported from New York by truck, arriving in time to be installed on the barge prior to the first pumping deployment on 12 March.

The CURB's beach gear, a normal element on its load list, was more than adequate for the task of laying and securing the mooring buoys. However, the only mooring lines initially available were four 7-inch circumference polypropylene ropes. There was concern that these lines might not be adequate. The principal worry with respect to equipment was the lack of a tug. It was feared that the CURB might not be capable of putting the heavy and awkward barge into the moor without the assistance of a tug.

Efforts to obtain a tug were unsuccessful. The task force headquarters did arrange, however, to make two LCM's available as a substitute. These two craft had been employed

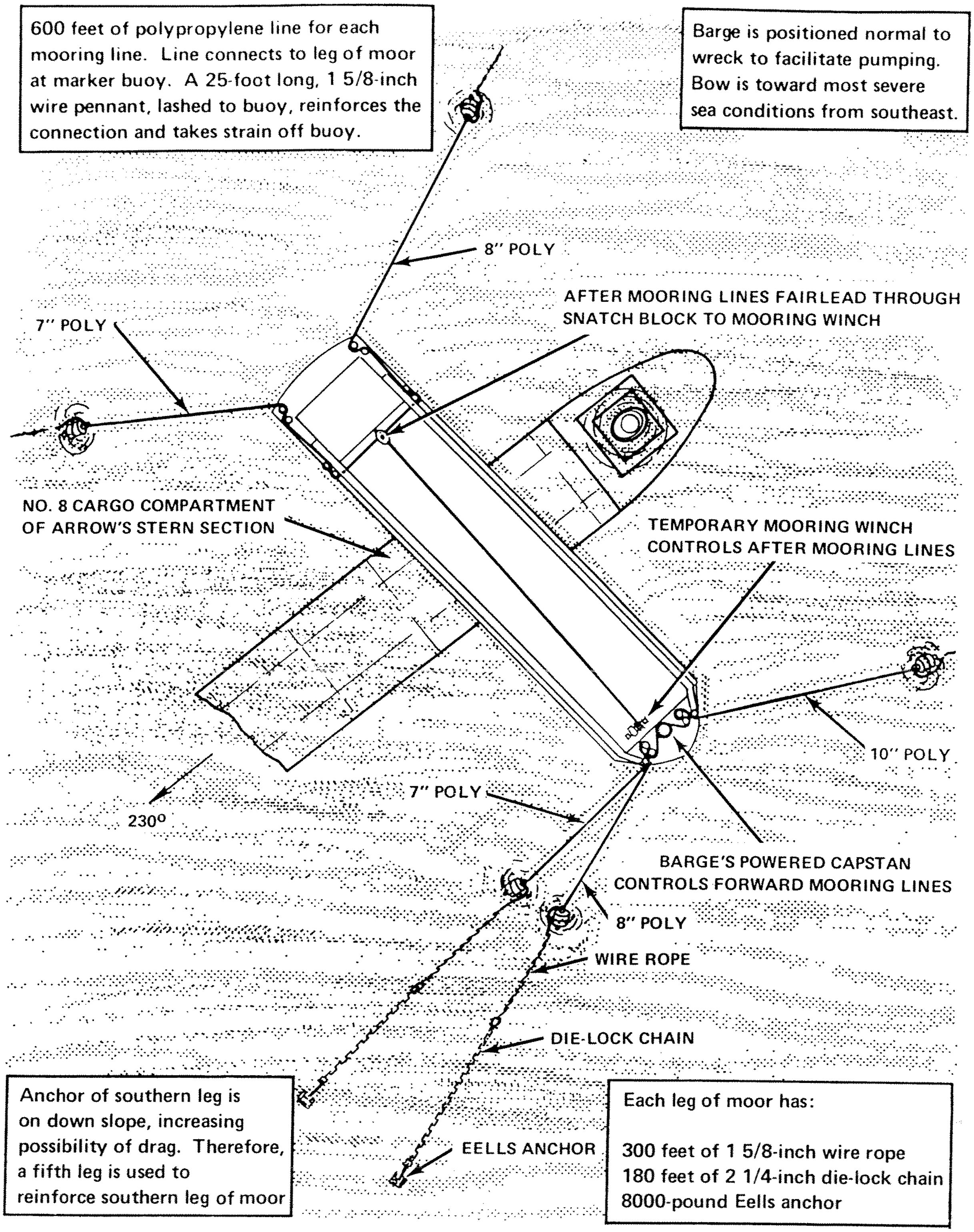


Figure 19. Diagram of Four-point Moor.

extensively in Arctic exploration work and subsequently removed from service. They were not, therefore, in the best condition for mooring tasks. In addition, their operators were inexperienced. Despite these limitations, the two LCM's performed valuable services in the operation.

MOORING PROCEDURES

As its first task upon arrival in the operational area on 2 March the CURB assumed responsibility for preparing and laying the moor. Rigging of the moor was accomplished before the outfitting of the barge could be completed. The CURB took advantage of the delay to deploy to the salvage site and lay the legs of the moor. A ring post on the wreck threatened to obstruct mooring operations, its top being only 6 feet below the surface. Divers from the YMT-12 destroyed it with explosives, removing the obstruction. This preparatory work was completed during the first week of the CURB's operations. The CURB then returned to Mulgrave to continue the effort required to get the barge ready for sea.

The CURB, towing the barge alongside, deployed to the salvage site on 12 March, a trip of about 3 hours. It took the better part of the afternoon to put the barge into the moor. Exceptional seamanship was required to maneuver the barge and to make sure the anchors would hold. Maneuver room was limited by the fact that the sunken ARROW was only 0.3 mile from Cerberus Rock. Wooden chips, one of the oldest but still highly effective mooring aids, were used to gauge relative speed and distance. The CURB controlled the barge's movements from the turning point on the port side and the two LCM's provided power fore and aft on the starboard side.

The mooring winch that was installed forward on the main deck of the IRVING WHALE was used to control the mooring lines to the after legs of the moor. These mooring lines were run through bollards on the stern and sides of the barge in order to fairlead them from the stern through a snatch block forward to the mooring winch. The barge's powered capstan on the bow was used to control the mooring lines to the forward legs of the moor.

ORIENTATION OF MOOR

In the first pumping deployment, the IRVING WHALE was placed in the moor with its bow to the northwest. The task force had established a meteorlogical service facility to provide information on weather conditions. Low pressure fronts in the Chedabucto Bay area often moved in from the Great Lakes basin down through the "slot" formed by the Canso Strait.

It was anticipated, therefore, that prevailing winds would be from this direction. Additionally, it was thought that heavy seas from the southeast occurred so seldom that there would be ample time to warn the CURB. The CURB planned to take the barge out of the moor and retire to a safe haven if wind conditions exceeded 30 knots.

Impact of Storm on 15–16 March

After several days of initial pumping operations, a major storm developed on 15 March. Worsening weather during the day forced a halt in pumping operations. However, the moor appeared to be holding well. Since the weather forecast predicted winds of only about 35 knots, the CURB decided to remain at the salvage site. During the night a southwesterly gale engulfed the area battering the IRVING WHALE with winds up to 70 knots and waves of 10 to 15 feet. These tremendous forces blew the barge out of the moor.

The two southernmost mooring lines gave way first. The barge swung around causing the two remaining lines to cross, creating the danger of chafing and weakening both lines. The hazard was eliminated by cutting one of the two lines. The IRVING WHALE then rode out the storm held by the one remaining mooring line and its own anchor underfoot.

It was too dangerous for the CURB to come alongside the barge during the storm. However, it stood by, ready to assist in case the barge broke loose. The following morning the weather cleared sufficiently by 1000 to permit the CURB to move close enough to the barge to throw over lines and take it under tow. Since the storm had coincided with the arrival of the RCN steam generator and additional suction hoses, the IRVING WHALE was towed back into Mulgrave to complete outfitting and prepare it for a more permanent-type moor.

Adjustments for Subsequent Moors

The stack of the ARROW was still intact during the first deployment. The barge had come very close to hitting it during the storm; this resulted in a decision to remove it before the barge was again placed in the moor. Divers from the YMT-12 destroyed it with explosives in the period 19-20 March.

The barge was moored and unmoored at the salvage site on two subsequent deployments. Some heavier line had been obtained and a combination of 7-, 8-, and 10-inch polypropylene lines were used on these occasions. A fifth leg was also laid on the southern side to give the moor additional holding power. Finally, the orientation of the barge was reversed. It was positioned in a southeast/northwest orientation with the bow seaward toward the southeast. No unusual problems were encountered in mooring or unmooring the barge on the last two deployments.

METHODS FOR HEATING AND LIFTING THE BUNKER "C"

The salvage master considered a wide variety of methods for debunkering the ARROW. He selected one primary method of heating and lifting the Bunker "C" from the different proposals under consideration. Several backup techniques were also developed and used, providing additional flexibility for the debunkering effort. The primary method and backup techniques are summarized in this section, preliminary to detailed treatment of their various features in subsequent sections. This section also addresses the planning considerations involved and reviews other methods which were considered but rejected.

PLANNING CONSIDERATIONS

The central problem at the outset of planning the salvage operations was the lack of reliable knowledge concerning the flow characteristics of Bunker "C" at the near-freezing temperature encountered in Chedabucto Bay. Captain Madsen described the problem facing him in early March as follows:

> We do not have accurate information on pumpability at lower temperature ranges. It is necessary to extrapolate from tables at higher ranges. I knew the oil would rise, but I didn't know its viscosity accurately at these low temperatures.

The lack of accurate information on pumpability at the lower ranges is primarily due to the fact that practical work in moving oil is done at the higher temperature ranges. There is normally no reason to deal with it at low temperatures. In extrapolating from tables at the higher ranges, it is also difficult to estimate viscosity reliably because small changes in temperature will cause large changes in viscosity. This characteristic, however, could be exploited in determining where heat should be applied to affect oil flow. That is, if the temperature of the Bunker "C" could be raised by only a small amount, there was promise that the flow rate could be increased sufficiently to make pumping a feasible proposition.

The three functions involved in predicting the flow rate were specific gravity, pour point, and viscosity. It was known that Bunker "C" had these characteristics:

Viscosity at 122°F	280 seconds (Saybolt Furol Seconds, SSF)
Pour Point	30°F
Specific Gravity at 60°F	0.964

The actual viscosity of the cargo oil was too high to be reliably estimated. It seemed probable that, unless it could be lowered by heating, it would be too sluggish to pump.

The temperature in the ARROW's tanks was assumed to be about 33° –34°F and the specific gravity of the Bunker "C" was estimated at 0.994. It was postulated, therefore, that the oil would rise because of the difference between its specific gravity and the specific gravity of salt water (1.024). The pressure on the deck of the wreck, assuming a full tank of oil open to the sea at the bottom, was calculated as about 120 pounds per square foot. On this basis, assuming that the oil could be heated sufficiently to reduce its viscosity, it was estimated that a discharge rate of about 100 barrels per hour could be achieved from each hose.

INSPECTIONS OF ARROW's CARGO TANKS

The salvage master obtained confirmation that the Bunker "C" would rise through divers' inspections of the ARROW's cargo tanks in late February. These inspections were conducted primarily to verify his preliminary estimates of the amounts of oil remaining in the various tanks. Divers opened the ullage covers on the tanks and observed whether there was any oil discharge. They then reported their visual estimates of the rate and volume of the discharge to the salvage master. By comparing their reports with his knowledge of the ship's original cargo and his previous assessment of damage, the salvage master was able to confirm, in large measure, whether there was sufficient oil in a tank to warrant a pumping effort.

These inspections also confirmed that the cargo tanks had been holed in the grounding and sinking and were open to the sea. This was important since it meant that the sea water in the tanks was acting against the Bunker "C" pushing it upward against the top of the tank. Had the tanks not already been holed, it was planned to introduce sea water by opening the sea suction valves where necessary.

SELECTION OF PRIMARY METHOD

Selection of the primary method for heating and lifting the Bunker "C" was based on the foregoing planning considerations and the knowledge gained from inspection of the ARROW's cargo tanks. The primary method (figure 20) was designed to accomplish the following:

Gain access to the ARROW's tanks. This involved drilling holes in the ARROW's deck with a hot tap drilling rig and attaching a gate valve connection for the cargo hose.

Heat the Bunker "C" in the cargo hose. This required fabrication of steam traces. Three different steam tract configurations were tried during the operation.

Pump the heated Bunker "C" to the tender. A steam supported pumping system was developed aboard the barge, IRVING WHALE, for this purpose. Steam generated for the pumping system was also used to heat the steam traces.

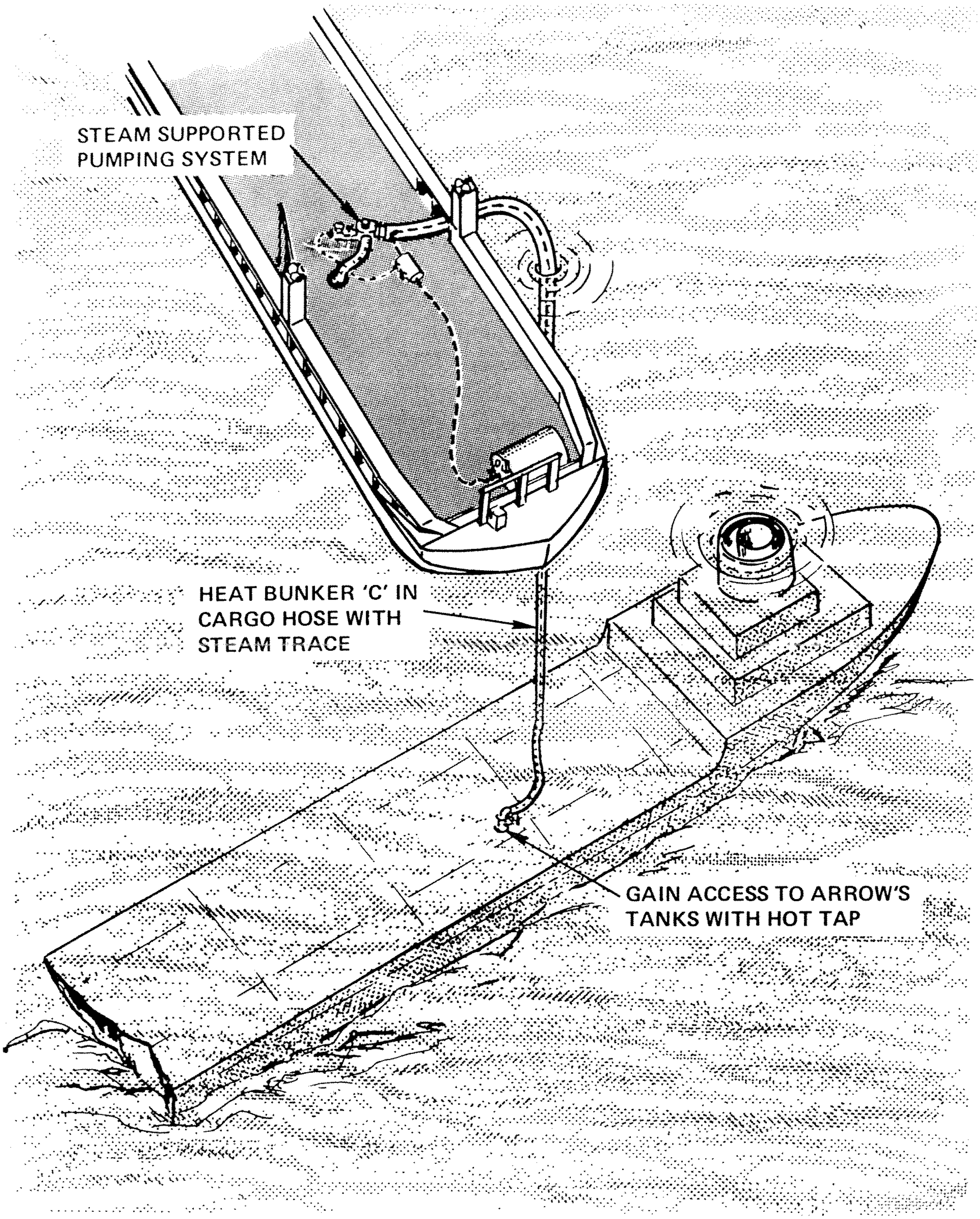


Figure 20. Primary Method for Heating and Lifting the Bunker "C."

The method combined both principle and expediency. The object was to use tested techniques and the most readily available equipment wherever feasible in order to get the salvage operation underway as soon as possible. Much of the equipment needed for the steam traces and the pumping system was available in the operational area. The CURB provided the rest. Equipment needed to gain access to the ARROW's tanks was also available or could be fabricated. The salvage force was experienced in the use of the pumping equipment, although not with the hot tap drilling rigs. The latter problem could be solved, in part, by testing and training prior to the salvage operation.

Assuming that the problem of gaining access to the ARROW's cargo tanks could be solved, the primary method appeared to be the most practical of all the various proposals that were under consideration. It exploited the use of reliable equipment that could be obtained without extensive delay. The steam pumping system gave the salvage master good chance of maintaining control over the progress of debunkering operations in the face of varying sea and weather conditions. And the primary method made specific provision for combatting the high viscosity of the cargo oil through its employment of steam traces to heat the sluggish oil in the cargo hose.

BACKUP TECHNIQUES

The decision to apply heat throughout the cargo hose with a steam trace was a crucial feature in developing the primary method. Introduction of steam into the gate valve area and into the cargo tank itself were also considered as means of heating the oil. Without the steam trace there would be a pressure drop across the entire hose length. With the steam trace, however, there would be a pressure drop only across the 6-foot area of the gate valve.

Although the steam trace was an essential feature, the salvage planners could not be certain that the process of releasing the Bunker "C" to rise through the cargo hose and heating it throughout the hose would produce an adequate pumping rate. Backup techniques for heating the oil were, therefore, developed. These included a technique for injecting steam into the gate valve area and another for injecting steam in the ARROW's cargo tanks.

The salvage force also made provisions to use an airlift as an alternative to the steam-driven pumps for lifting the heated Bunker "C." There was substantial operational experience to draw upon in considering the airlift technique. This experience, however, was confined largely to the lifting of solid materials. Little was known about airlifting a liquid such as Bunker "C." It was decided, therefore, to use the airlift method as a backup technique rather than using it as the primary means of lifting the oil.

These backup techniques provided flexibility in executing the overall salvage plan and made alternatives avaliable to reinforce or replace the techniques for heating and lifting the oil in the primary method. All of them were used to some extent during the course of the operation although none played a major role in influencing its outcome.

CONSIDERATION OF OTHER METHODS

Proposed methods for heating and lifting the oil came from many sources in the early stages of planning. Some were ruled out quickly as being impractical. Others were investigated more thoroughly before being rejected. Proposals that were considered and eventually rejected include the following:

- Cofferdams
- Horizontal drilling of tank tops
- Use of oil as a heat source

Cofferdams

The principal disadvantage of the primary method with its reliance on a steam pumping system was slowness. Cofferdams offered the potential advantage of greatly accelerating the debunkering operation. Large diameter, 36-inch piping was located in the area for possible use as construction materials. However, the logistics and engineering problems involved in attempting construction of a cofferdam were formidable. The sea states that were expected to be encountered were also deemed too severe. Even if construction had been practicable, cofferdams would have afforded no way to keep the oil discharge under positive control as the pumping method did. The proposals for use of cofferdams were, therefore, discarded early in the planning stage.

Horizontal Drilling of Tank Tops

The tank tops on the ARROW's cargo tanks were raised fittings about 4 feet above deck level. The possibility of tapping the sides of these fittings rather than penetrating the tanks vertically through the deck received extensive consideration. It was visualized that a suction hose could be attached to one side of the tank top and a steam hose to the opposite side. With such an arrangement a steam lance could be aimed directly toward the opening of the suction hose. The steam flowing horizontally across the hatch area would provide maximum heating and lifting effect. The relative positions of the steam outlet and suction inlet would produce a highly efficient application of the steam. This method, when used in conjunction with a steam trace in the cargo hose, would minimize or eliminate the pressure drop across the gate valve area.

Inspection of the tank tops raised doubts as to the strength of these tank tops to withstand the pressure of tapping and pumping. Moreover, the Cox gun that was available was too powerful for use in installing studs in the thin fittings. A diver fired a stud into the side of a tank top to determine the practicality of tapping and attaching a hose connection. The stud penetrated all the way through and out the other side. The tank tops were old and rusty. There was fear that they might spring a leak. This method would have also required the fabrication of curved or rolled connections to properly fit the sides of the tank tops, which, although feasible, would have been time consuming. For these reasons, this method was finally rejected in spite of its potential.

Use of Oil as a Heat Source

It was believed at first that oil from the IRVING WHALE could be used as a major source of heat for the oil trapped in the hulk of the ARROW. The concept for application of this method was simple. The cargo heating system of the IRVING WHALE would be used to heat waste oil in its cargo tanks. The hot oil would then be pumped down into the ARROW through a hot tap. The hot oil would mix with the Bunker "C" at the top of the tank and raise its temperature sufficiently to permit pumping. A second tap would be made for the attachment of the suction hose. A steam trace would be used with this method to maintain heat in the suction hose as the oil flowed upward.

There was no operational experience to assure that this method would work. It was not at all certain that the hot and cold oil would mix under these conditions because of the differences in gravity and viscosity. Nor was it clear that a sufficient volume of heated oil could be pumped into tanks that might be intact and nearly full. Scientists attached to the task force headquarters, working in conjunction with Canadian laboratory facilities, undertook the task of confirming the feasibility of this method. In the interim, preparations went forward to apply this concept (figure 21).

Preparations focused on tank 8C, the first target of oil recovery operations. Two hot taps were made on this tank. Two gate valves were installed and two hose rigs were assembled. It was decided, however, to begin pumping operations with the primary method first. This initial pumping effort was successful, using only the closed loop steam trace as a heat source. Concurrently, the study effort ashore confirmed that the probability of adequate heat transfer was low and that the hot oil injected into the tank would probably not mix with the Bunker "C." Therefore, the use of hot oil as a heat source was not attempted.

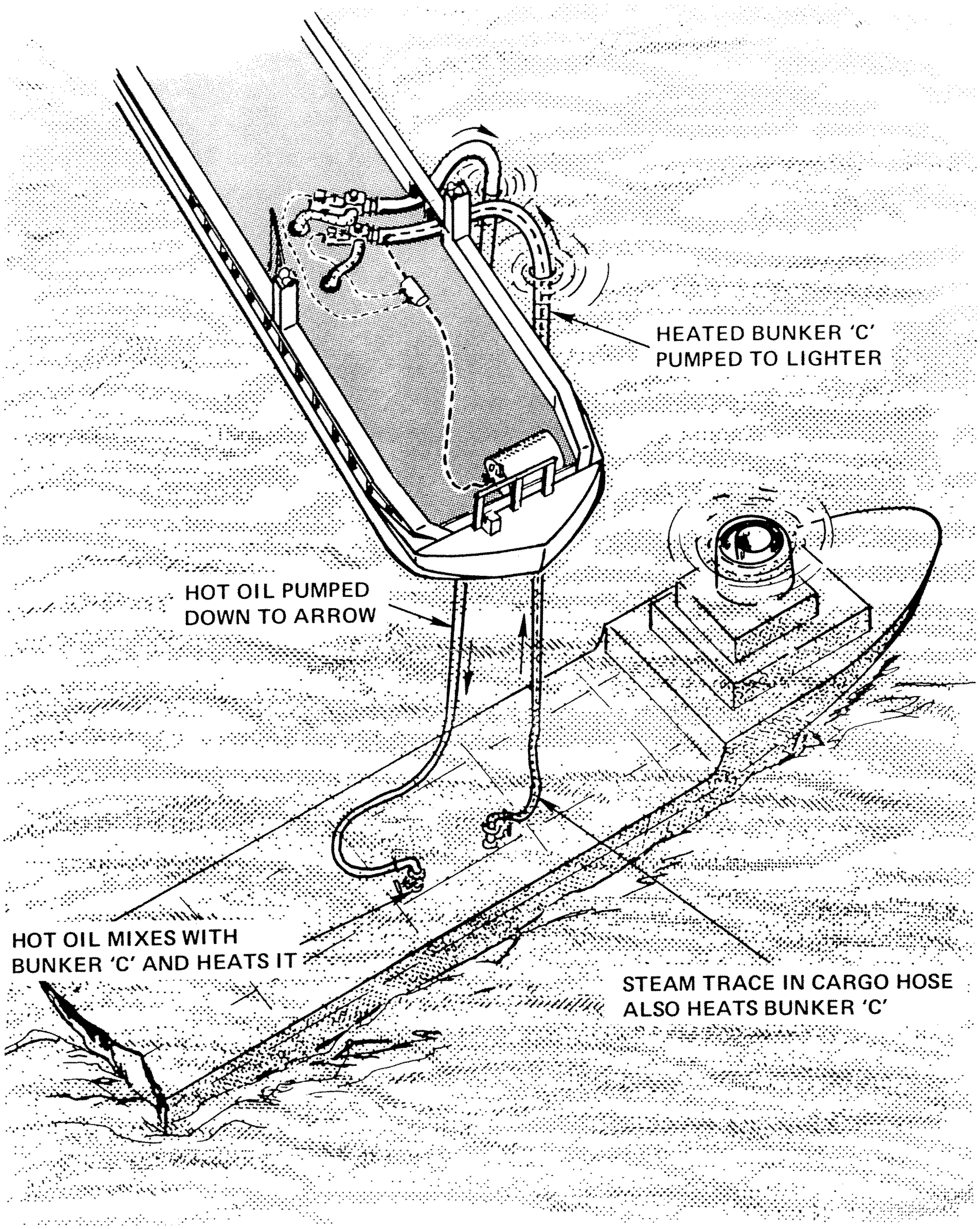


Figure 21. Hot Oil as a Heat Source (Concept Considered but not Used)

GAINING ACCESS TO THE ARROW'S CARGO TANKS

To establish the feasibility of recovering the ARROW's cargo, it was first necessary to solve the problem of gaining access to the ARROW's cargo tanks. This was a critical problem. Oil had never before been salvaged from a sunken tanker. There was no precedent that could be applied directly. The problem had two aspects (1) a method for penetrating the tanks had to be found, and (2) suitable fittings for attachment of the suction hoses had to be provided.

THE HOT TAP METHOD

Captain Sven A. Madsen provided the solution in mid-February. Pondering the problem, he recalled the principles of the "hot tap" method that had been used for many years in the oil industry to drill holes in high temperature oil refinery pumping systems while maintaining the flow of oil during drilling. This method involved the use of an enclosed rotary cutter or "hot tap" machine. Although Captain Madsen had never seen this type of drilling rig, he knew of its existence and reasoned that it could be used under water to penetrate the ARROW's deck in order to reach the cargo tanks.

In discussing the problem with representatives of the Imperial Oil Company in Halifax, Captain Madsen learned that a hot tap machine was available as well as an operator experienced in its use. He then consulted the RCN Diving School, located nearby at Dartmouth, and arranged for experiments off the Imperial Oil Company's pier. RCN divers successfully penetrated a steel plate in 30 feet of water, establishing that the method was workable.

In addition to demonstrating the feasibility of using the hot tap machine under water, the experiments in Halifax served two other highly useful purposes. RCN divers gained valuable training in application of the method. They thus had a vital foundation of experience upon which to build when they began diving operations in Chedabucto Bay. Further, the experiments provided an opportunity to address the matter of assembling and installing the necessary fittings on the ARROW's deck for operation of the machine and for attachment of suction hoses for pumping.

The technique as applied to the salvage operation required that the cutting operation be conducted through a gate valve attached to the deck above the cargo tank. The gate valve arrangement provided positive control over the opening in the deck to prevent upward discharge of oil caused by the pressure differential between the Bunker "C" and the sea water beneath it. The base of the gate valve sat on a spool piece which was first bolted to the tanker's deck. A suction hose was then connected to the gate valve via a 90° elbow fitting after the drilling rig was withdrawn.

COMPONENTS AND FITTINGS

The components and fittings involved in the application of the hot tap technique to gain access to the ARROW's cargo tanks and provide hose connections are as follows:

Spool Piece	Hot Tap Machine (rotary cutter)
Gate Valve	90° Elbow Fitting

Spool Piece

The spool piece is a simple standpipe, 14 inches high with an 8-inch internal diameter. This component, used as the first link to the ARROW's cargo tanks, was fabricated especially for the salvage effort in accordance with specifications provided by Captain Madsen. A total of 13 spool pieces were attached to the ARROW's decks during the operation. They came to be known and commonly referred to as "Madsen Flanges."

The upper flange of the spool piece has a standard ASA 8-inch pipe flange hole pattern for mating to the gate valve. The lower flange had to be fabricated to meet two unusual requirements. First, it had to be appreciably wider than the upper flange in order to provide working room for firing in the studs at as nearly a vertical position as possible. Secondly, additional width was also needed to ensure the necessary stability at the interface between the flange and the deck where a severe tension load was expected. A rubber gasket was cemented to the base of each spool piece to provide a seal between the flange and the deck.

Two different models of the spool piece were designed and used (figure 22). Eight of the 13 spool pieces installed were the simple model without any fittings. Five were constructed with a 2-inch pipe fitting and valve. These latter models provided a backup capability of introducing steam into the cargo tank or the gate valve area in the event that the heat received from the various steam trace configurations should prove inadequate. Steam was only injected through these fittings on two tanks for a brief period of time with inconclusive results.

A Cox underwater explosive stud gun was used to fire threaded studs into the deck of the ARROW through the 12 holes in the lower flange of the positioned spool piece. With the threaded studs thus installed, nuts were then screwed onto the studs to make the spool piece secure. It was estimated that a spool piece secured in this manner could withstand 12 tons of tension load. A notched wooden plug was positioned over each hole in the flange to help position the Cox gun for firing.

The spool pieces attached to the ARROW's deck were blanked off and left in place as pumping operations were concluded. This ensured that any oil residue that might remain in the tanks would not escape. The spool pieces would also be available for future use should the amount of residue warrant a renewal of pumping operations.

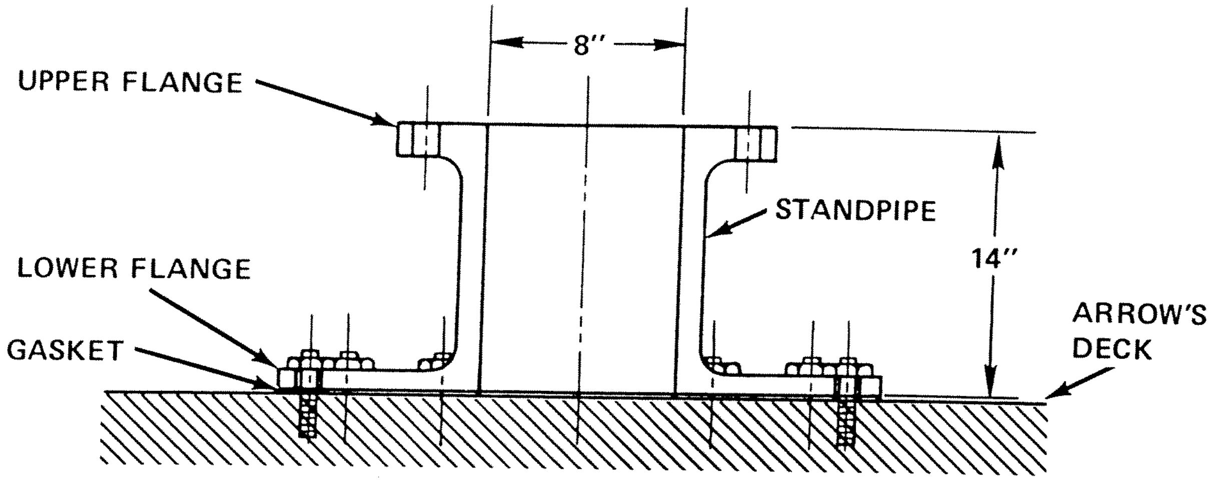


Figure 22. Spool Piece (Madsen Flange).

Gate Valve

The gate valve (figure 23), 8 inches in internal diameter, is a disc type valve that withdraws fully from the valve opening when the "gate" is opened, allowing passage for the cutting head and shaft of the hot tap machine. The gate valve played a crucial role both during the hot tap procedure and throughout the pumping operations since it enabled the divers to control the flow of oil at its source. The first gate valves used were obtained from the Imperial Oil Company Refinery in Halifax; others were purchased locally in Port Hastings through a retail outlet of the Gulf Oil Company.

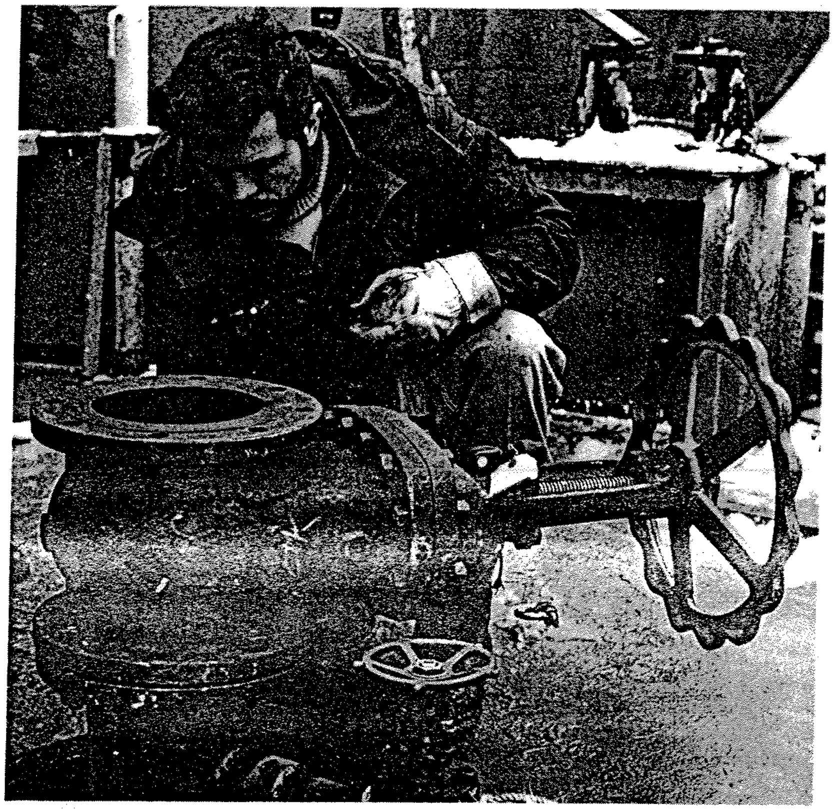


Figure 23. Gate Valve Mounted on Spool Piece.

Hot Tap Machine (Rotary Cutter)

The hot tap machine, built by D. Williamson Incorporated of Tulsa, Oklahoma, is approximately 5 feet long and 10 inches in outer diameter. It weighs approximately 500 pounds. Two versions of this cutting tool were used. The first, a pneumatic drilling rig (figure 24), was obtained from the Imperial Oil Company. The second version, with a hydraulic system, was requested for backup because it was thought to be more reliable for underwater work in the environmental conditions that were encountered. It was procured by the Canadian Department of Transportation. Neither machine was self contained. Each machine required an umbilical

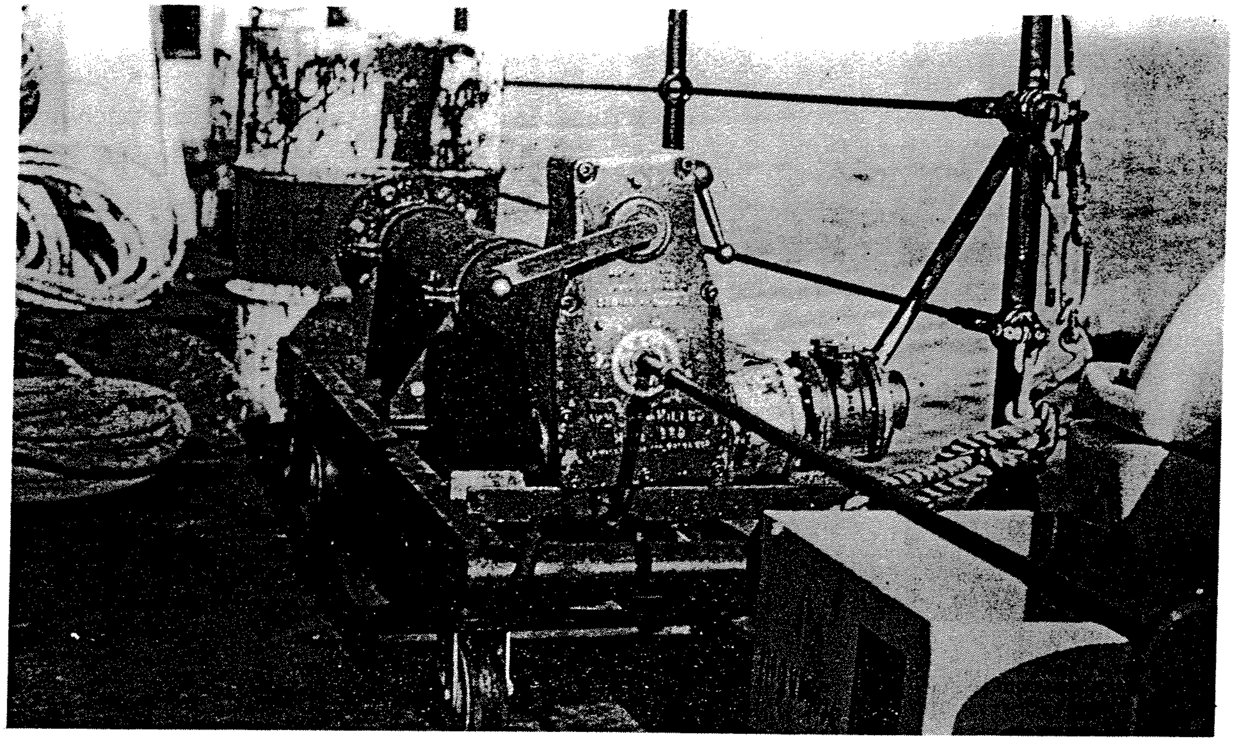


Figure 24. Air-Driven Hot Tap Machine on Handling Dolly.

cord to its power source on the surface. Both machines were supported from the YMT-12, which served as the tender for the hot tap operations. The air-driven machine was hooked up to the ship's compressor. The other machine was powered by a gasoline-driven pump that provided hydraulic fluid at 500-600 psi.

The hot tap machine is first flange mounted to the gate valve (figure 25). The gate valve is then opened and a manually operated gear mechanism on the machine is used to lower the cutting head through the gate valve and spool piece. After achieving penetration, the cutting head with the cut piece of steel is withdrawn and the gate valve closed.

A view of the fully assembled rig is shown in figure 26. This photograph and the preceding views of the mounting procedure suggest that the various components of the hot tap apparatus were preassembled on deck before lowering them to the wreck. There were actually two different techniques used for assembling the components. The first was to preassemble the components as shown in the photographs. As operations progressed, the divers gained more experience with the apparatus and devised a second technique in which components were lowered separately and the apparatus was assembled underwater on the deck of the ARROW after the spool piece had been attached. Both techniques were effective. The second technique facilitated handling the components. With both techniques, air-filled drums were used to help control the equipment under water. Flotation devices were used extensively for handling heavy equipment as ground swells on the surface often hampered the lowering of gear.

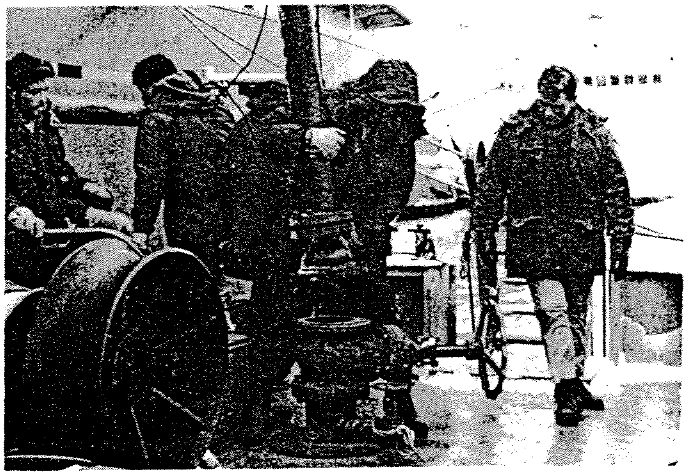
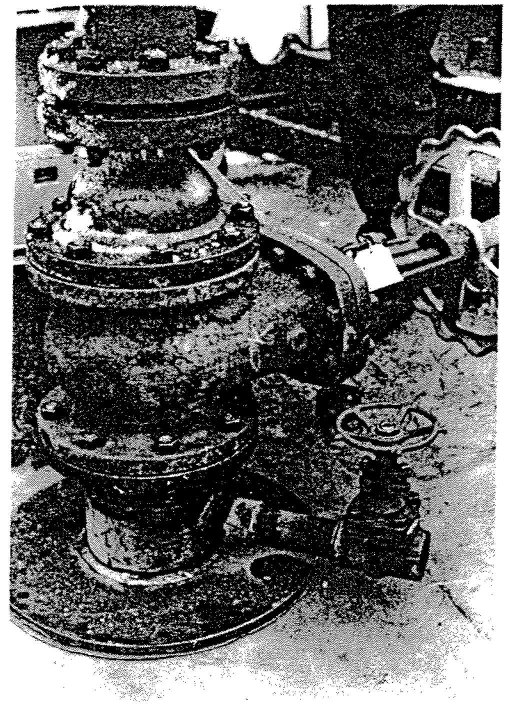


Figure 25. Mounting of Hot Tap Machine on Gate Valve.



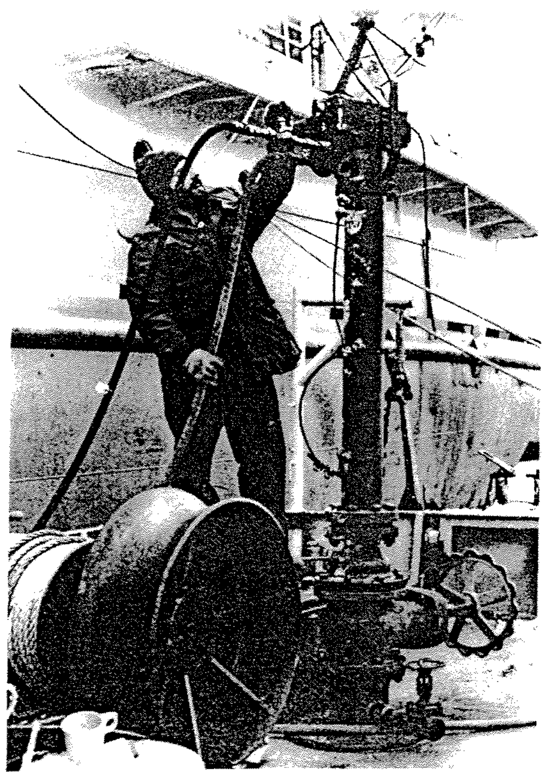


Figure 26. RCN Diver Adjusting Valve on Hose of Air-Driven Hot Tap Machine.

These drilling rigs are basically capable of cutting a doughnut-shaped cylinder, 3 inches thick and 7-1/2 inches in diameter, from a steel plate. This penetrating power was more than adequate since divers had determined that the deck thickness of the ARROW was 3/4-inches for its center tanks and 5/8-inches for its wing tanks. The cutter itself is composed of a central guiding shaft that bites into the surface first and provides guidance and leverage for the cutting teeth on the circumference of the cutting head. The cutting teeth achieve the 7-1/2 inch diameter penetration through rotating action. The shaft has recessed detentes or "barbs." These detentes extend outward when penetration is achieved and provide the basis for lifting the cylinder from the hole as the shaft is raised when cutting is completed. The cutting head fits into a flanged housing at the bottom of the drilling rig which provided the necessary 8-inch connection to the gate valve. Details of the assembly are shown in figure 27.

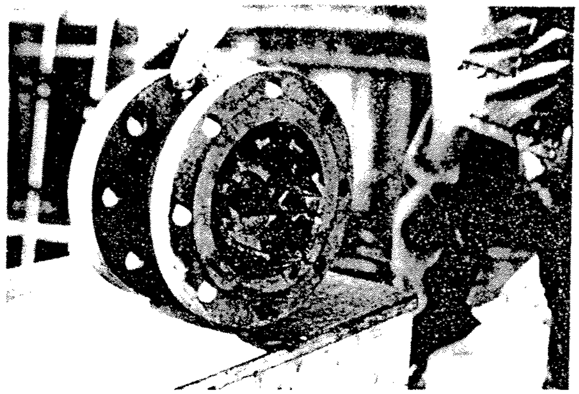
Elbow Fitting

After penetrating the deck, withdrawing the rotary cutter, and closing the gate valve, one final step remained before the assembly was completely prepared to receive the 8-inch or 6-inch cargo (suction) hose for pumping–an elbow connection had to be installed on top of the gate valve. The origin of the idea to use an elbow fitting indicates the degree to which suggestions for improving techniques and solving problems emanated from all sources in the task force. The idea was first proposed by a diver from the YMT-12 during preparations for connecting the first tank for pumping.

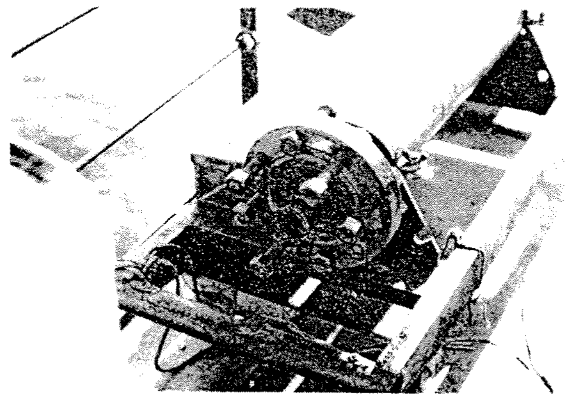
The diver reasoned that a 90° elbow fitting would reduce the tension load on the spool piece. It would also facilitate securing the cumbersome hose to the gate valve by permitting a horizontal connection rather than a vertical connection. There was much less interference from waves and swells in making the horizontal connection. The 90° fitting also permitted the divers to lay the hose on the ARROW's deck, thus providing additional stability. The first fitting used was taken from IRVING WHALE and was actually a 180° fitting with a swivel joint. The remaining fittings were 90° rigid fittings procured ashore.

OPERATIONAL ASPECTS

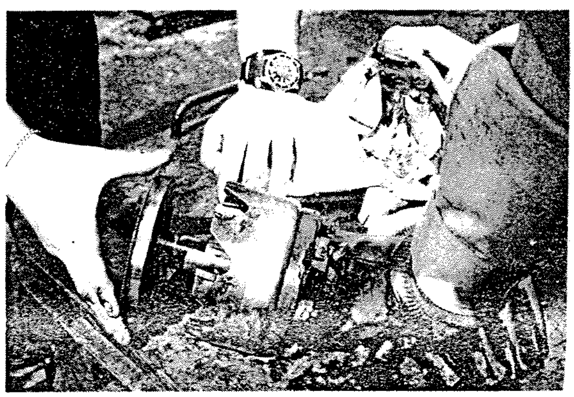
The task of penetrating the ARROW's decks and installing the related fittings and hoses posed formidable problems for the RCN divers from YMT-12. Diving conditions were dangerous and difficult. Divers had to contend with near-freezing temperatures, frequent storms and adverse sea conditions, and the continuing difficulty caused by oil seepage about the wreck. The oil affected their face masks, regulators, and suits; oil saturation caused the wet suits to lose their insulating ability. Therefore, routine work schedules were not possible. Frequent modifications were required and the problem of available bottom time was a central factor affecting pumping progress throughout the operation.



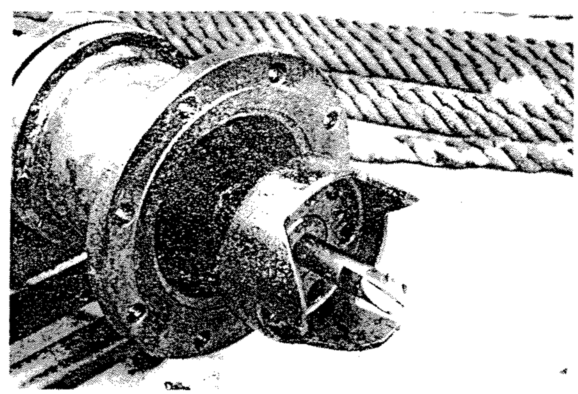
Cutting head and drilling bit recessed in flanged housing.



Flanged housing is bolted to base of drilling rig. Drill bit is connected to shaft at base of rig.



Cutting head is bolted to drill bit. Note the piece of steel cut from ARROW's deck.



This assembly was also used. Note slightly different design features and removal of cutting teeth.

Figure 27. Details of Cutting Head Assemblies Used with Hot Tap Machines.

The selection of proper locations for the hot taps was complicated by the lack of a detailed plan of the location of internal structural members of the ARROW's hull. The ship's prints did not reveal the locations of all the members as the deck had been renewed since the original construction. As a result, longitudinal beams under the ARROW's deck were struck on the first four hot taps attempted. These obstacles added significantly to the divers' required bottom time, although they were ultimately successful in breaking the weld between the deck and the beams in three instances. The most reliable method of avoiding the longitudinals was eventually found to be simply by tapping the ship's deck with a hammer.

Divers worked and experimented with the hot tap machines continuously in an effort to improve their reliability for underwater work. The machines were well conceived and designed; however, they were topside pieces of equipment. Considering this fact, they performed surprisingly well in the underwater environment. Several modifications had to be made on the hydraulic rig before it could be made to operate satisfactorily in the cold water. These modifications were made in consultation with the manufacturer's representative. Divers also experimented with the cutting head, removing some of the teeth in an attempt to get better performance. The most successful modification to the cutting head appeared to be one in which every other tooth was removed.

The pneumatic machine presented difficulties early in the tapping operations when the air vanes and air hoses kept freezing. In addition, the clutch shaft on this drill parted on two occasions. Repair of the shaft was time consuming since it had to be taken to the Port Hawkesbury Shipyard. The maintenance problems encountered with the hydraulic machine were mainly with it's supporting gasoline-driven pump rather than with the drilling rig itself.

A total of 13 taps were made during the operation on 9 different tanks. Certain tanks, such as tanks 8C, were tapped twice early in the operation when it was envisioned that a double tap would be needed to remove the oil. The majority of tanks required only one tap. In one instance, on tank 8S, a second tap was necessitated when the first failed to penetrate.

The scope of the work effort involved in preparing one tank for pumping is indicated in Table 4, which presents estimates of bottom time and divers needed to perform each task. About 7 hours were needed to complete the hot tap and hook up all the necessary connections. The table illustrates the technique by which the hot tap apparatus is assembled under water. The overall time required was about the same when the apparatus was preassembled topside.

Table 4. Work Effort Entailed in Preparing One Tank for Oil Pumping Operations.

TASK	DIVERS REQUIRED	HOURS OF BOTTOM TIME (EACH DIVER)
Install Spool Piece	1	1
Lower and Attach Gate Valve	2	1
Lower and Attach Hot Tap Machine	2	1
Perform Cutting Operation	1	1
Withdraw and Raise Hot Tap Machine	2	1
Lower and Install 90° Elbow Fitting	2	1
Lower and Attach Suction Hose	2	1

PUMPING SYSTEM ABOARD THE IRVING WHALE

DEVELOPMENT OF PUMPING CAPABILITY

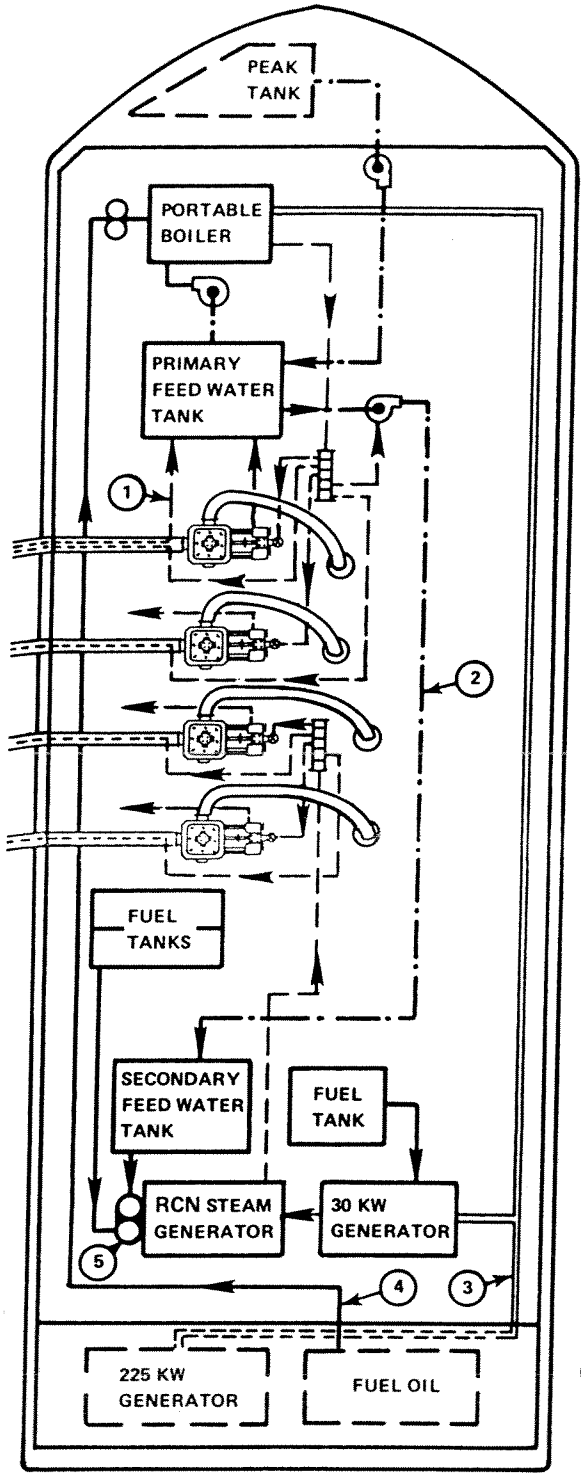
It was decided early in planning to equip the IRVING WHALE with a multiple pumping capability. An estimated 30,000 to 50,000 barrels of Bunker "C" remained in the ARROW's tanks. As many as 13 different tanks might have sufficient oil to warrant pumping. This large amount of oil and the probability of its location in so many different tanks led to the development of a requirement for six pumping stations aboard the barge.

The factor of time was also crucial in estimating the pumping capability that would be needed. It was highly probable that bad weather would be encountered. The shorter the time required for pumping, the less would be the likelihood of disruptions caused by bad weather. The longer the oil remained in the wreck, the greater would be the probability of further major oil spills. The expense of the operation itself could be reduced by reducing the time needed for pumping. All these considerations were important in determining the need for as many as six pumping stations on the IRVING WHALE.

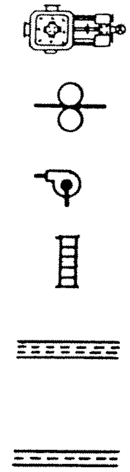
This multiple capability could not be achieved at the outset since all the necessary equipment was not immediately available in the Chedabucto Bay area. A partial capability was developed in time for the first pumping attempt during the initial deployment, 13-16 March. The full capability was then achieved during the interval in port at Mulgrave, 16-21 March, prior to launching full-sclae pumping operations. A maximum of four pumping stations were operating simultaneously during the peak of the salvage effort.

PUMPING SYSTEM

The pumping system that was developed to achieve the full capability required for extended operations was built around two steam power plants. The barge's fuel and electricity were used to support the forward power plant, which was the first to be installed. The after power plant, which was more elaborate than the forward one, had its own fuel and electrical supply. Feed water was stored in the barge's peak tank and pumped to feed water tanks on deck that fed the two boilers. The boilers supplied steam to reciprocating salvage pumps that were set up in pumping stations amidships. The recovered oil was pumped directly into the barge's cargo tanks. This system is shown schematically in figure 28.



SYMBOLS



SALVAGE PUMPS

FUEL PUMP

FEED WATER PUMPS

STEAM MANIFOLDS

CARGO HOSE WITH CLOSED LOOP STEAM TRACE

CARGO HOSES WITH OPEN STEAM TRACES

NOTES

(1) THE FORWARD SALVAGE PUMP AND CLOSED LOOP STEAM TRACE EXHAUST TO TANK TO HEAT FEED WATER. THE OTHER PUMPS EXHAUST TO ATMOSPHERE

(2) FEED WATER PUMPED AFT BY 2-INCH STEAM DRIVEN PUMP

(3) THE BARGE'S 225 KW GENERATOR OR THE TEMPORARY 30 KW GENERATOR COULD SUPPORT EITHER OR BOTH STEAM POWER PLANTS

(4) COPPER TUBING FUEL LINE FOR FORWARD BOILER

(5) SERVO MODULATOR ON RCN STEAM GENERATOR CONTROLLING BOTH FUEL AND FEED WATER

Figure 28. Schematic of Pumping System Aboard IRVING WHALE.

Steam-Driven Duplex Pumps

The CURB brought with it five 6-inch steam-driven duplex pumps (figure 29). These were reciprocating pumps. Although old, they were highly reliable, heavy duty, general purpose rigs suitable for pumping the Bunker "C" at the expected conditions of temperature, viscosity, and pressure. The pumps were not a normal element on the CURB's load list. They were available in the Murphy Pacific Marine Salvage Company warehouse in New York City. The Murphy Pacific salvage master, anticipating the possible need for their use, had them put aboard the CURB before it sailed from New York for Chedabucto Bay. These five pumps performed all the pumping from the ARROW to the IRVING WHALE. A sixth pump was procured locally but the opportunity to use it did not arise.

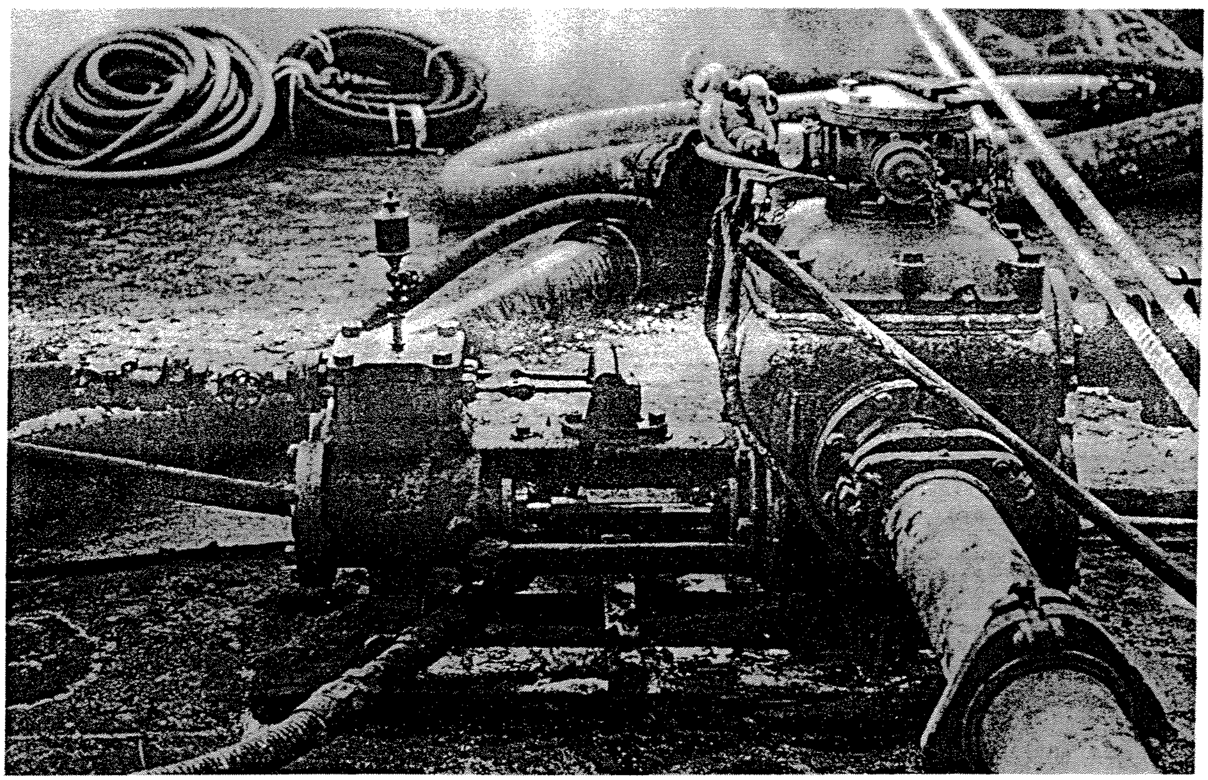


Figure 29. Steam-Driven Salvage Pump.

Cargo Hoses

The cargo or suction hoses used for connecting the pumps aboard the barge to the ARROW's tanks were heavy duty 8-inch and 6-inch discharge hoses in 30- and 35-foot lengths.

There were sufficient hose sections available during the first pumping deployment to assemble two hose rigs for connecting to the ARROW. These were 8-inch hose sections that had been procured from Newfoundland. However, one pumping station was actually connected and used during this initial deployment.

Four additional rigs of 6-inch hose were obtained from the Port Hawkesbury Shipyard for subsequent pumping deployments. These were the principal rigs used for the remainder of the operation. The 8- and 6-inch sections were used in combination on certain pumping stations, with one section of 8-inch hose being connected to the pump and the rest made up with 6-inch hose sections. The 6-inch hose was lighter and easier to handle than the 8-inch hose. Both types of hose provided more than adequate capacity for the pumping rates that could be achieved. In some instances the connection to the pump was made with a 6-8 foot length of metal piping. This rigid connection facilitated deployment of the hose and minimized the probability of the initial suction pressure collapsing the fuel hose near the pump.

Considerations in Rigging and Handling the Cargo Hoses

The depth to the ARROW's deck was 51 feet with a tidal range of 5.5 feet. This meant that a minimum of 2 hose sections or 60 feet would be needed just to provide a straight up and down connection to the surface with no free hose. The first hose rig used was 90 feet in length. Although this arrangement worked adequately, it was considered that additional length should be provided to ensure a reserve to account for swells, bad weather, movement of the barge in the moor, etc. Some additional length would also be needed to reach tanks that were not directly under the barge. Accordingly, the salvage master shifted to lengths of 120 feet for the subsequent rigs, using a rule of thumb calculation of 2 feet of hose for each foot of depth. The 90° elbow fitting on the cargo tank allowed the bight of the hose to lie on the deck of the ARROW. The hose was not lashed or otherwise secured to the deck because securing it would have tended to reduce the flexibility afforded by the additional length.

The pumping stations were generally set up amidships on the deck of the IRVING WHALE (figure 30). The barge had 6-foot high gunwales which posed a problem in hose handling. The salvage crew cut openings between the ribs of the gunwales to provide passages for the hoses. Use of these openings facilitated laying the hose and reduced the probability of crimping. In addition, they reduced the height to which the oil had to be lifted, thus facilitating pumping operations. The sections cut out of the gunwale were replaced at the conclusion of the operation.

Maneuvering the heavy and cumbersome hose rigs and manhandling them underwater to make the connections to the gate valves and 90° elbow fittings on the ARROW's cargo tanks was no easy task for divers from the YMT-12. Their first attempt to hook up a cargo hose took more than 4 hours. Based on this initial experience, they developed a general procedure that

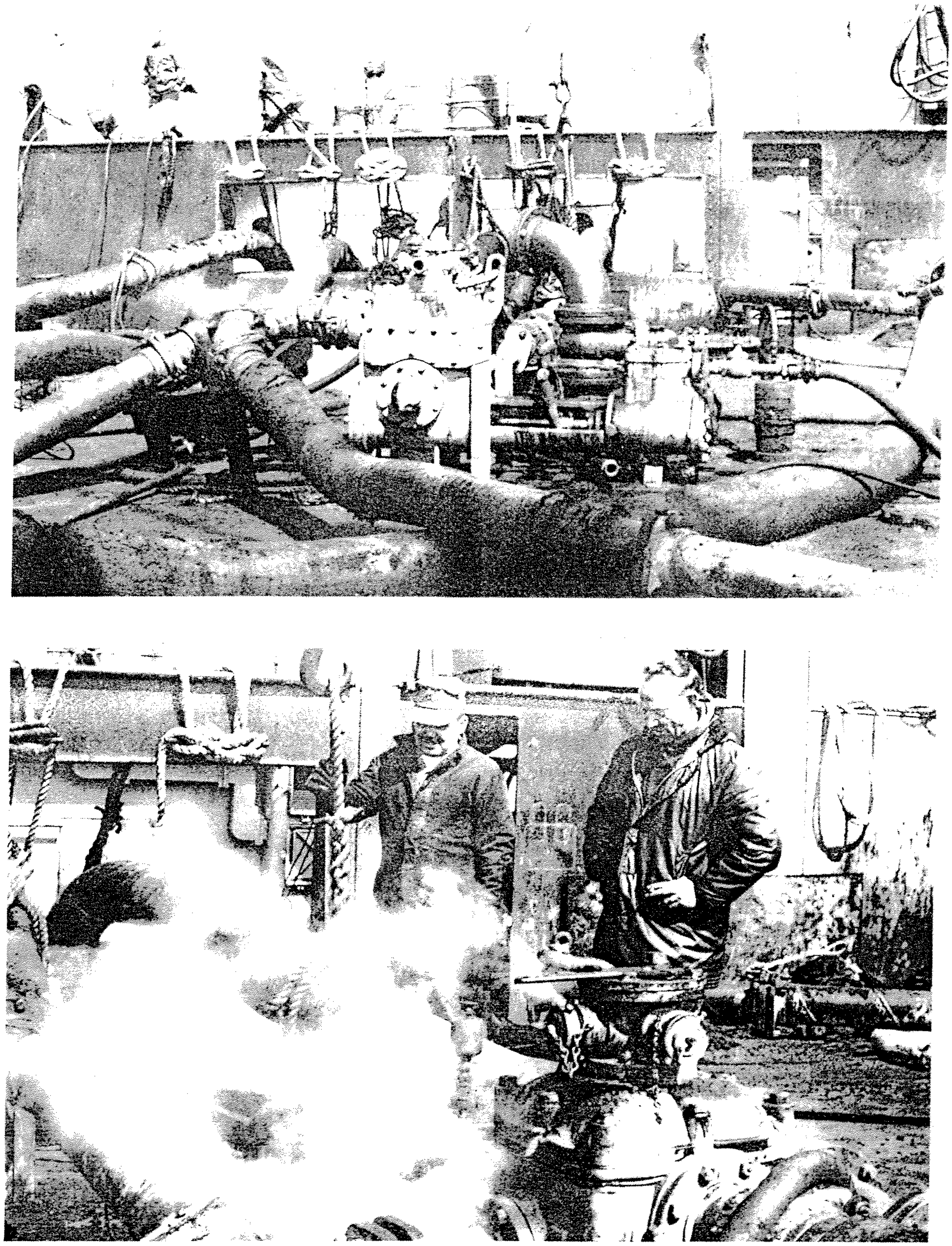


Figure 30. Views of Pumping Stations Aboard IRVING WHALE.

significantly shortened the bottom time required for this task. A jackstay was attached between the barge and the elbow fitting below. The end of the hose was then secured to the jackstay with a strap and shackle and the hose rig lowered to the ARROW using the jackstay as a guideline. In some cases, where it was necessary to clear the sag of the hose over the catwalk or other obstructions, the hose was secured in more than one place to the jackstay. Flotation barrels were also put to good use in manhandling the hose rigs in the water.

On those occasions when bad weather was imminent or when the barge had to be taken out of the moor, the cargo hoses were disconnected from the pumps, capped, and slipped overboard. The lower ends were left connected to the ARROW's tanks. The hoses were buoyed with retrieving wire and drums to help the divers recover them when pumping was resumed. This procedure was not always a simple matter. The disconnected hoses sometimes became entangled in the wreck and it was difficult to free them so that they could be brought topside.

Lifting the hose rigs in the air and maneuvering them on the deck of the barge required careful handling. Their great weight could easily cause crimping if they were not lifted properly. Recovering the hose rigs normally involved the use of both of the barge's booms as well as the mooring winch that had been installed on the forward deck area. The two booms were alternated, first one lifting the hose a short distance and then the other pulling it aboard. The sequence was then repeated. The winch was used to pull the rigs to the desired position on deck.

STEAM POWER PLANTS

Since the IRVING WHALE did not have a steam generating capability, procurement of power plants became a matter of highest priority at the outset of planning the salvage operation. Steam would be needed to support the pumping system and to heat the Bunker "C" by means of various steam trace configurations. Contacts were initiated with every available source of supply in the Chedabucto Bay area to locate possible power plants.

Portable Boiler

The only available power plant located locally as a result of the search was a portable, 120-horsepower, scotch marine tube boiler, manufactured by the Cleaver Brooks Company of Milwaukee, Wisconsin (Model Number CB-621-80). It had a rated capacity of 150 psi. The boiler had been used in road construction work by an asphalt paving company in New Glasgow. It was an old rig and had obviously seen many years of service. Moreover, it had not been used in a long time and required a great deal of work to make it operational. There was, in fact, only one person in the area who was at all familiar with its workings. He was a veteran fireman who had formerly tended the boiler for the paving company. The task force located him and brought him out of "retirement" to help get it running.

RCN Steam Generator

The second power plant obtained was an industrial, servo-modulated steam generator, larger and more sophisticated than the portable boiler. It was a 300-horsepower installation, manufactured by the Vapor Clarkson Company of Chicago, Illinois (Model Number FA2-4748-YHJ). This plant was borrowed from the Royal Canadian Navy shipyard at Halifax. It was not available initially and consequently was not used during the first pumping deployment.

Need for Two Power Plants

There were two reasons for procuring and operating two different power plants. It was estimated that the first or portable boiler could sustain only two pumping stations and steam traces at a time. The second, or RCN steam generator, was, therefore, needed to increase the multiple pumping capability from two to six stations, the load predicted for the climax of debunkering operations. The second reason was to provide a backup in the event of boiler failure. The backup capability proved to be important as problems were encountered throughout the operation in keeping both plants operational.

Installation of Portable Boiler

The portable boiler was positioned in the forward deck area of the IRVING WHALE (figure 31) where it would be near the barge's peak tank that was to serve as the basic source of feed water. The barge's fuel tanks and 225 KW generator that were to support the boiler were all the way aft, below decks. It was reasoned, however, that fuel lines would be much less likely to freeze than feed water lines. Positioning the portable boiler near its feed water source would reduce the probability of feed water freezing in the lines.

An automatic fuel regulator valve was installed and a fuel line, requiring more than 300 feet of copper tubing, was laid along the deck to connect the boiler with the barge's fuel supply. This fuel line proved to be too small to bring up maximum pressure during the first deployment. There were also problems with vacuum leaks at the joints in the line. It was replaced with a larger capacity line during the refitting period at Mulgrave.

Installation of RCN Steam Generator

Unlike the portable boiler, the RCN steam generator did not operate on the diesel fuel that was readily available in the barge's fuel tanks. It burned a grade 2 fuel oil. Consequently, this boiler required its own fuel service tanks that had to be installed on deck. It was necessary to resupply these tanks from drums, a laborious and time consuming procedure particularly in view of the high fuel consumption.

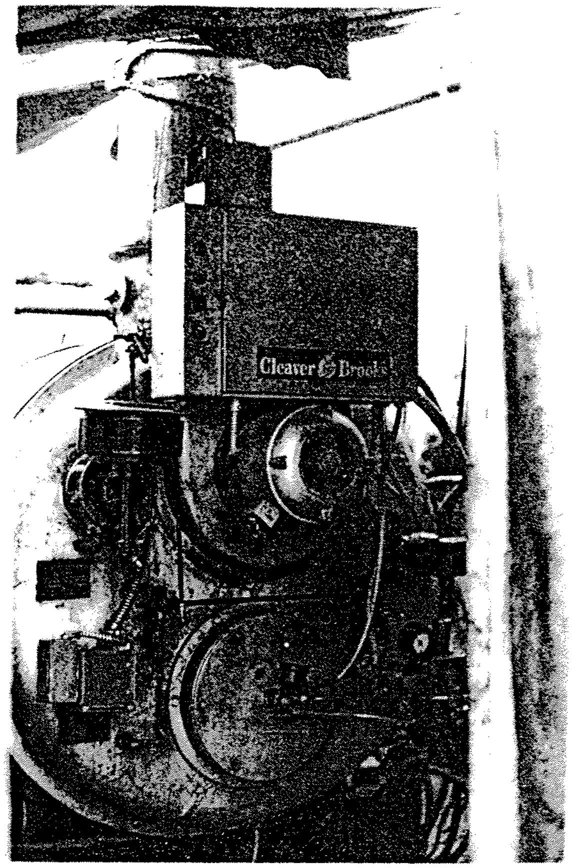
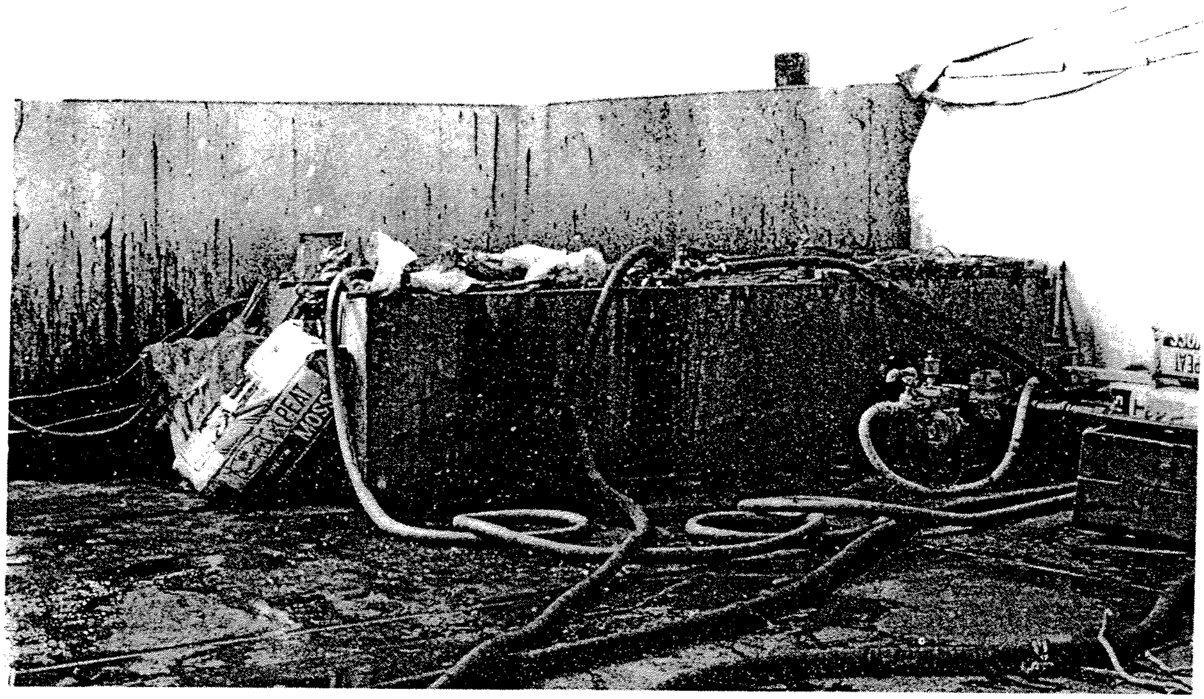


Figure 31. Cleaver Brooks Portable Boiler.

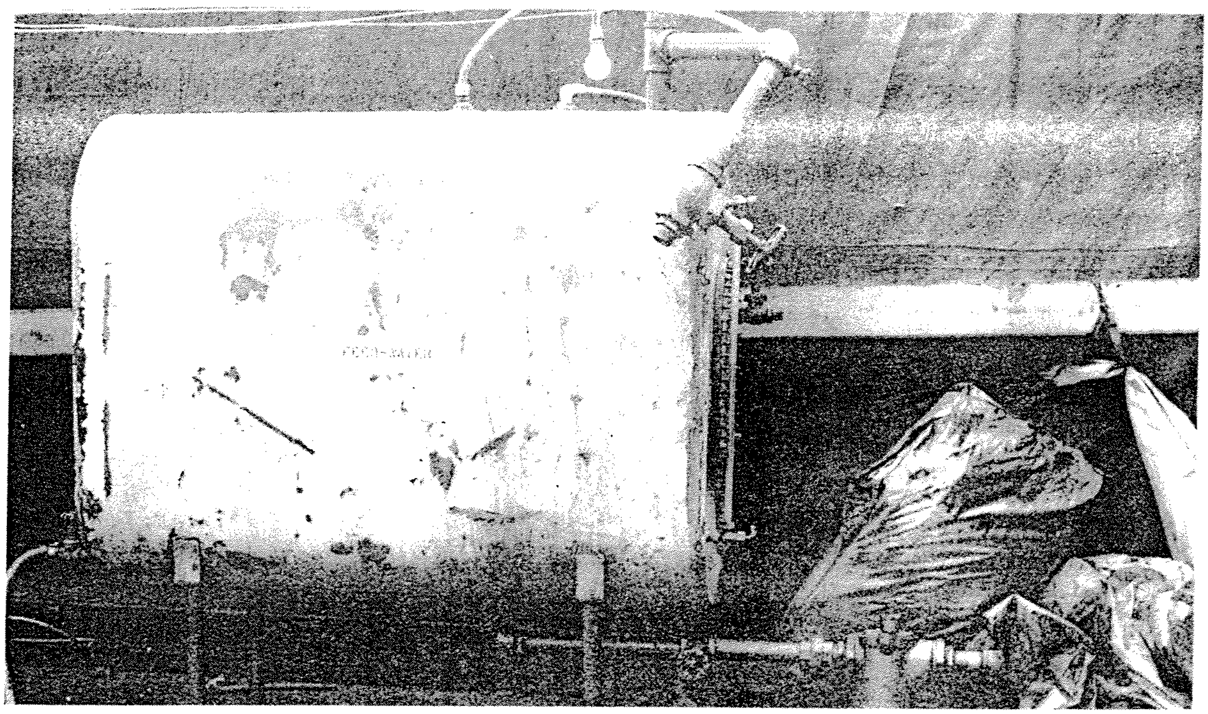
FEED WATER TANKS AND LINES

A feed water tank was initially positioned just aft of the portable boiler to support the forward power plant. This tank, approximately 10 feet long, 6 feet wide, and 4 feet in height, ultimately served as the primary feed water tank for both power plants. A steam pump was used to pump the feed water from the barge's peak tank to the primary feed water tank where it was fed to the portable boiler. Another steam pump was used to pump the water from the primary feed water tank to a smaller, secondary feed water tank that supported the RCN steam generator. The two feed water tanks are shown in figure 33.

Two methods were used to heat the feed water. Exhaust steam was bled into the primary feed water tank to heat the feed water to 80–85°F. This was done in an attempt to improve the efficiency of boiler operations as well as to keep the feed water from freezing. A second method was to marry the feed water line running aft to the RCN steam generator with steam exhaust lines. This was done by simply lashing the two hoses together. The latter method helped significantly to keep water from freezing as it passed over the cold deck of the barge.



Primary feed water tank, installed forward, supporting both steam power plants.



Secondary feed water tank, installed aft, supporting RCN steam generator.

Figure 32. Feed Water Tanks Aboard IRVING WHALE.

OPERATING PROBLEMS WITH THE PUMPING SYSTEM

A variety of mechanical and electrical breakdowns occurred throughout the operation. Both the portable boiler and RCN steam generator failed on several occasions. The IRVING WHALE's 225 KW generator and the 30 KW diesel electric generating set supporting the RCN steam generator also went out of commission periodically. The effective logistic support devised by the task force headquarters at Port Hawkesbury contributed significantly to the solution of these maintenance problems. Replacement parts and technicians were made available quickly in response to requirements levied by the salvage master. The ingenuity of members of the salvage crew also helped to minimize the impact of these breakdowns.

The operating problems were caused by the environment and by the emergency conditions under which the salvage force had been assembled rather than by any inadequacies or limitations in equipment design. The RCN steam generator was more highly automated than the portable boiler; this created maintenance difficulties when malfunctions occurred in the servomechanism that controlled both its fuel and its feed water intake. Conversely, the portable boiler, although somewhat easier to repair, was older and, as a result, basically less reliable. The principal difficulties, however, arose as a result of the primitive conditions aboard the barge and the speed with which the equipment had to be located, assembled, and made operational.

Feed Water Problems

There was no time, for example, to make provisions for the highly purified chemically controlled condensate that is normally used as boiler feed water. Potable, fresh water was used instead with recognition and acceptance of the attendant risks of less efficiency and greater wear on the equipment. The barge's peak tank, in which the feed water was stored, had never been used and consequently became the source of rust and sediment that mixed with the feed water and turned it to the color of orange juice.

As pumping progressed, the feed water became further contaminated with Bunker "C" that was picked up in the exhaust steam lines of the pumping system. The design of the steam-driven salvage pumps is such that exhaust steam leaving the pump had to "see" the oil being pumped. Some pickup is therefore inevitable. Since water conservation was critical, exhaust steam was bled back to the primary feed water tank to conserve water. Bunker "C" in the exhaust mixed with the feed water at that point. Seawater was also being pumped with the oil and this contributed to the contamination. Initially, boiler tenders drilled holes in the sides of the primary feed water tank near its top to allow the oil to drain out. Later, they cut open the tank top and used buckets to dip out periodically the oil floating on top of the feed water. Improvisations of this kind were applied repeatedly throughout the salvage effort to keep the pumping system in operation.

The great consumption of feed water by the two steam power plants required substantial logistic efforts to replenish the IRVING WHALE's peak tank. The consumption rate reached 5000 gallons per day as the multiple pumping stations were put into operation during the second pumping deployment. The CURB returned to Mulgrave on two occasions to fill its water tanks and then transfer the water to the barge. The ARCTIC SHORE, an oil rig tug, was also employed to top off the barge at the salvage site. The logistic effort involved in supplying feed water of adequate quality and quantity is perhaps the principal limitation in the use of steam systems as a source of heat and power. It is a limitation that is normally overcome through the use of permanent, fixed installations aboard ship. When such installations are not readily available and must be rigged on a temporary, makeshift basis as for the ARROW salvage effort, this limitation becomes particularly significant.

Generator Problems

The effectiveness of the task force headquarter's logistic support system was demonstrated midway during the second pumping deployment when the IRVING WHALE's 225 KW generator went down. This generator supplied power for the barge's lighting system, cargo oil heating system, and for its hydraulic booms as well as for the portable boiler. It was, therefore, a vital element in the salvage effort. The onboard operators could not account for the breakdown. Accordingly, the CURB notified the operations control center of the task force headquarters which, in turn, contacted the RCN shipyard at Halifax. Technicians were flown in by helicopter and were aboard the barge working on the problem within a few hours.

The technicians observed that there was no excitation current on the generator and traced the problem back to an automatic voltage regulator that needed replacement. Arrangements were initiated with the Ainsworth Electric Company of Toronto to bring in a replacement regulator. Since this would require 2 days, the technicians devised a temporary expedient to get the generator operating. They rigged 12-volt batteries in series to provide an excitation current of 32 volts, sufficient to energize the main fields of the generator. This expedient kept the generator in operation until the new voltage regulator could be installed.

The 30 KW diesel electric generating set supporting the RCN steam generator also broke down during this period. It kept hunting and could not stabilize its load. The governor in the fuel supply system was initially thought to be the source of the difficulty. However, the representative of the USN Supervisor of Salvage diagnosed it as a fuel starvation problem caused by a faulty filter. His diagnosis proved correct when the filter was replaced and the generator put back in operation.

The importance of providing redundancy in the pumping system was demonstrated by the alternating failures of these two generators. In one sequence, with the 225 KW generator down, the 30 KW generator was put into the barge's power system by jumpers. Then, when the 30

KW generator went down, the same jumpers were used backwards to supply power to the 300 Hp Vapor Clarkson steam generator. Both the portable boiler and the RCN steam generator were used interchangeably to support the various pumping stations. Therefore, although the different breakdowns often prevented the pumping system from operating at its full capacity, they did not force a halt in pumping for any appreciable period of time. In one way or another the salvage force usually managed to keep at least two pumps in operation.

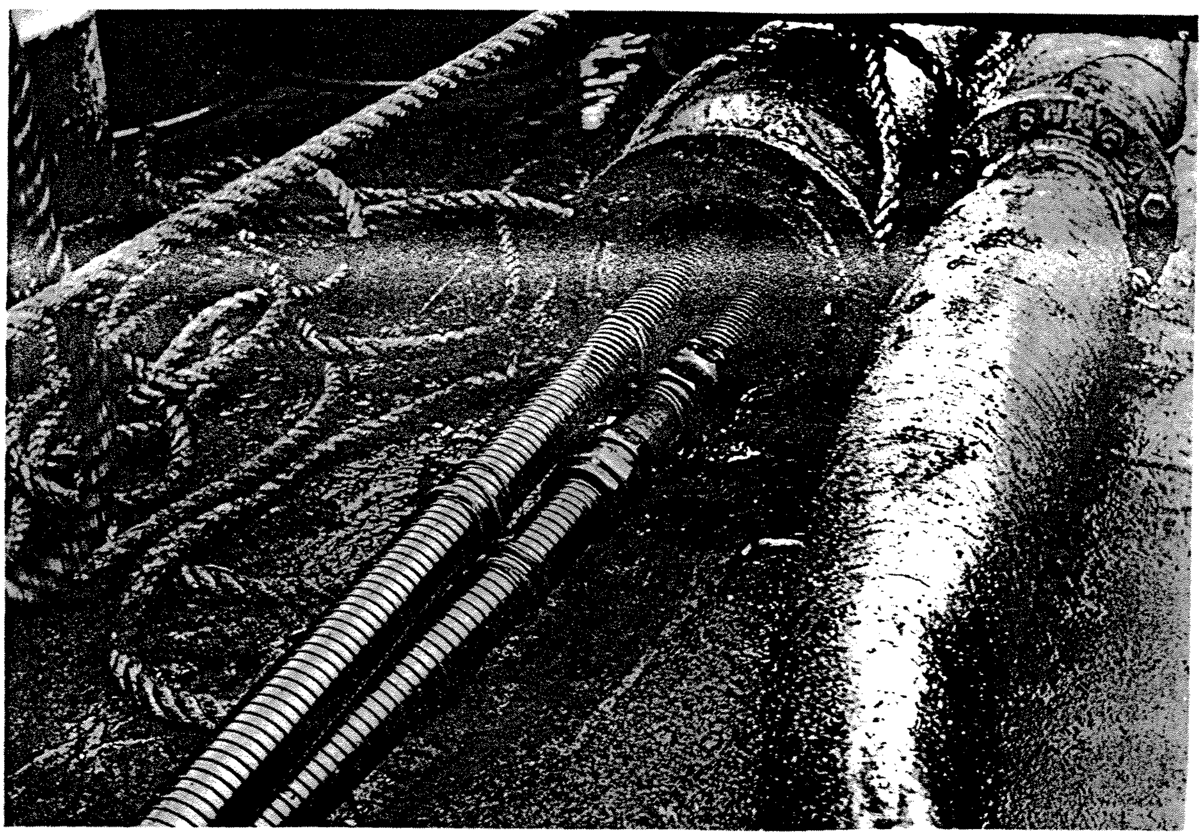


Figure 33. Convoluted Metal Hose Used for Fabricating Steam Traces.

STEAM TRACE CONFIGURATIONS

GENERAL

All cargo hoses used during the operation were steam traced. Steam tracing consisted of inserting a 1½-inch diameter flexible metal hose inside the 6-inch and 8-inch diameter cargo (suction) hoses. The surface of the metal steam hose was convoluted (figure 33) to add to its heat transfer capabilities. Saturated steam at 100 psi and 300°F was circulated through the metal hose to heat the Bunker "C" as it flowed upward through the cargo hose to the tanks of the IRVING WHALE. Heating was considered necessary not only to facilitate oil flow inside the cargo hose but also as a precautionary measure. Should it be necessary to discontinue pumping for any reason, it was feared that oil in the hose could block further flow if it were allowed to become too cold. The steam trace provided insurance against such an eventuality.

The metal hose of the steam trace did not extend beyond the bottom end of the suction hose. Although extension below the suction hose itself would have provided heat in the critical area of the gate valve connections to the ARROW's cargo tanks, it posed a major potential disadvantage should a cargo hose rupture. A rupture would have caused an immediate oil spill. With the metal coil inserted through the open gate valve, there would have been no way to shut the valve to stop the escape of the oil. The steam trace was, therefore, terminated near the bottom end of the cargo hose.

Given the difficulty of accurately estimating the flow characteristics of the cargo oil and predicting pumping rates under the operational conditions in Chedabucto Bay, the installation of steam traces was a small investment in time and effort which promised big dividends. The metal hoses could be assembled rather easily and their insertion into the cargo hoses was a relatively simple matter. To be sure, the increased steam consumption put an additional load on the pumping system. The load, however, was within the capabilities of the system that had been developed for driving the salvage pumps. The steam requirements for heating the oil in the cargo hoses did not impede the progress of pumping operations.

The salvage master relied on the steam traces throughout the operation as the principal means of heating the cargo oil. Steam tracing, because of its importance and the extent to which it was used, emerged as a major feature of the primary method of heating and lifting the Bunker "C"; along with the steam supported pumping system and the technique for gaining access to the ARROW's cargo tank.

CONFIGURATIONS USED

The three steam trace configurations that were used (figure 34) are as follows:

Closed-Loop Steam Trace

Open Steam Trace with J-Fitting

Open Steam Trace with Straight Fitting

The closed-loop steam trace differed significantly from the other two. It was a double trace, closed-loop, whereas the other two were single traces, open at the bottom of the suction hose. The first configuration circulated steam and condensate through the loop back to the barge and discharged it into the primary feed water tank. The other two configurations were essentially similar; they discharged steam and condensate into the Bunker "C." The second configuration had a 180° fitting or J -connection at its opening that pointed the discharge in the same direction as the flowing Bunker "C." The third configuration had a straight fitting at its opening that directed the discharge of the trace into the critical area of the gate valve connection.

All three configurations probably produced comparable heat transfer effects throughout the length of the cargo hose. It was assumed that much of the heat would be transferred on the downward path of the trace and that the steam would largely condense at the bottom of the cargo hose. The first two configurations were fabricated from old materials and consequently susceptible to leakage at various points along the cargo hose. The traces for the third configuration were made up of new materials and apparently did not leak. The effects of the leaks in the first two configurations could not be evaluated, although it was theorized that leaks near the top of the closed-loop trace may have reduced pumping efficiency by exerting downward pressure in the cargo hose. In actual application, it appeared that varying mixtures of steam and condensate were discharged from the open traces.

The CURB's salvage force fabricated the first two configurations in response to specifications prescribed by the salvage master. The double or closed-loop steam trace was made first and used on tank 8C during the first pumping deployment, 13-15 March. There were only one boiler and two cargo hose rigs available at this time. The second or J-connection configuration was assembled for use in the second hose rig. The Port Hawkesbury Shipyard fabricated the other traces that were used. These were delivered, along with the four cargo hoses that had been ordered, during the refitting period at Mulgrave. These traces had J-fittings. The CURB's salvage force removed the J-fittings and attached straight fittings thus forming the third of the three steam trace configurations used. The traces were tack welded to the cargo hose to increase the stability of the steam coils.

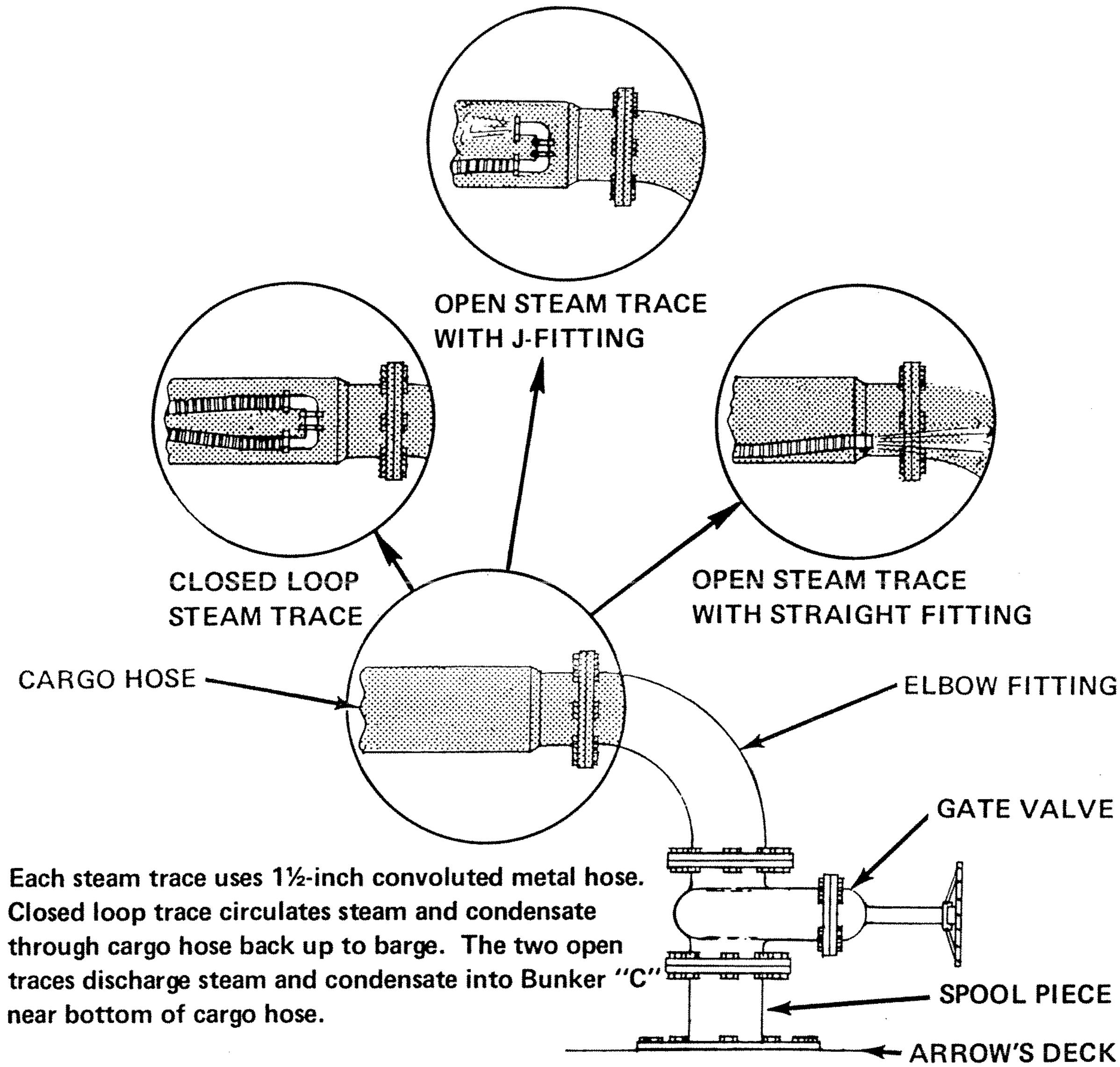


Figure 34. The Three Steam Trace Configurations.

THE CLOSED-LOOP STEAM TRACE

The principal reason for using the closed-loop steam trace configuration initially was the need to conserve water. Additionally, the salvage force could not be certain of the effects of using open traces, although they offered more heating potential in theory. The main purpose was to put a system in operation as quickly as possible that would fulfill the basic requirement of heating the Bunker "C" in the cargo hose. The closed-loop trace met this requirement. Views of this configuration are shown in figure 35.

The successful use of the closed-loop trace on tank 8C during the first pumping deployment was important in that it demonstrated that the pumping system would work. The temperature of the Bunker "C" as it reached the IRVING WHALE was 117°F., confirming that this configuration produced a substantial heat transfer within the cargo hose. This trace continued to be used in subsequent pumping deployments to complete debunkering from tank 8C. It was also used briefly on tank 8P.

THE TWO OPEN STEAM TRACES

The open steam traces were designed to exploit the affinity of western heavy fuel oils for water. It is comparatively easy to achieve emulsion with fuel oils such as Bunker "C." If emulsion could be achieved, then the viscosity of the oil could be reduced quickly. This was the key to the open trace configurations, although it was also conceived that there would be some heating and agitating effects by discharging the mix of steam and condensate into the oil at the bottom of the suction hose.

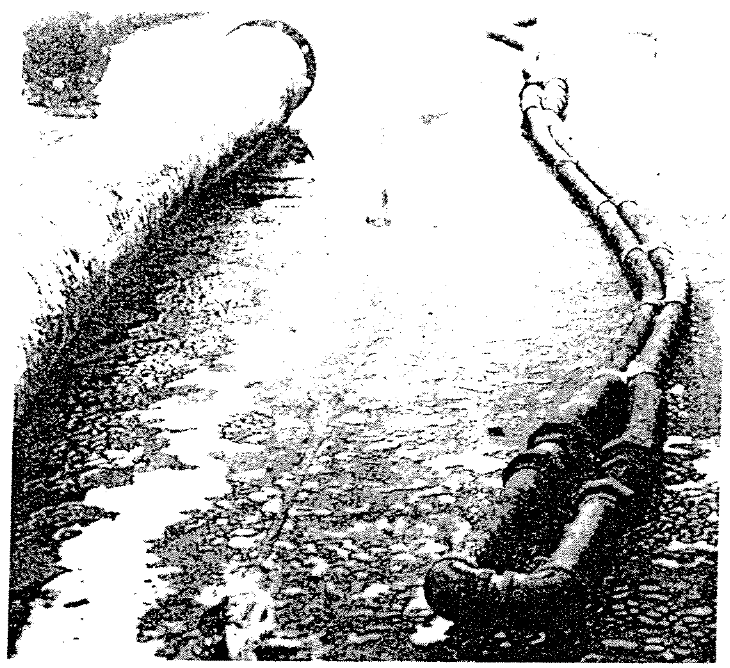
The second or J-connection configuration was used only briefly, primarly in conjunction with airlifts. Introducing the discharge in the same direction as the oil flow might boost the flow as well as lower the viscosity by mixing with the oil. The third configuration was the most extensively used. The straight, outward discharge was intended to maximize the mixing and heating effects in the critical area of the gate valve. This configuration was used in the three hose rigs that were used to pump oil from tanks 7P, 7C, 7S, 8S, 9C, and 6S.

The promise of achieving increased discharge rates was the principal reason for the switch from the closed-loop steam trace to the open configurations. It seemed clear that they would work at least as well and possibly better than the original configuration. The deliberate introduction of condensate into the oil was not a matter of concern since the ARROW's cargo was not being salvaged for its commercial value but rather to prevent further pollution in the Chedabucto Bay area.

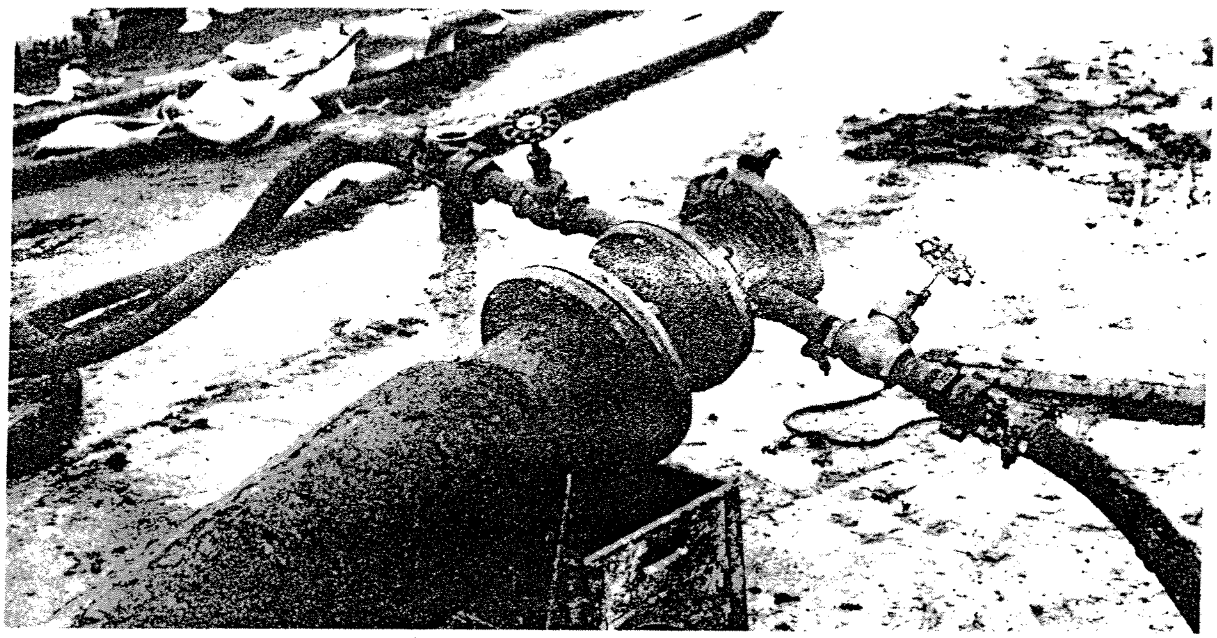
EFFECTIVENESS OF THE THREE CONFIGURATIONS

The operational conditions during the oil recovery effort precluded reliable quantitative comparisons of the relative effectiveness or the three steam trace configurations. The focus of

Fitting at bottom of suction hose.



Steam trace alongside suction hose.



Inlet and outlet connections at top of suction hose.

Figure 35. Views of Closed-Loop Steam Trace.

attention was always on the salvage problem. There was neither the intent nor the opportunity to set up controlled conditions to measure the efficiency of any of the various techniques which were tried.

There was, in particular, no way to relate temperatures of the recovered oil as measured for each configuration and the pumping rates. All three steam traces definitely produced heat transfer within the cargo hoses. The temperatures of the oil recovered through the various hoses were consistently well above 100°F. The pumping rates varied throughout the operation depending on the efficiency of the two steam power plants. Hoses rigged with the straight, open traces were pumped at rates in the range of 100 to 150 barrels per hour. Hoses with the other two steam traces were pumped at somewhat lower rates.

The deliberate introduction of steam and condensate into the oil at the bottom of the suction hose by means of the two open configurations appears to have been an effective technique for reinforcing the flow rate. The closed-loop trace did have the advantage of conserving water. But the open traces probably made better use of the mixture of steam and condensate at the bottom of the suction hose by discharging it into the Bunker "C" rather than circulating it back upward through the hose as did the closed-loop configuration.

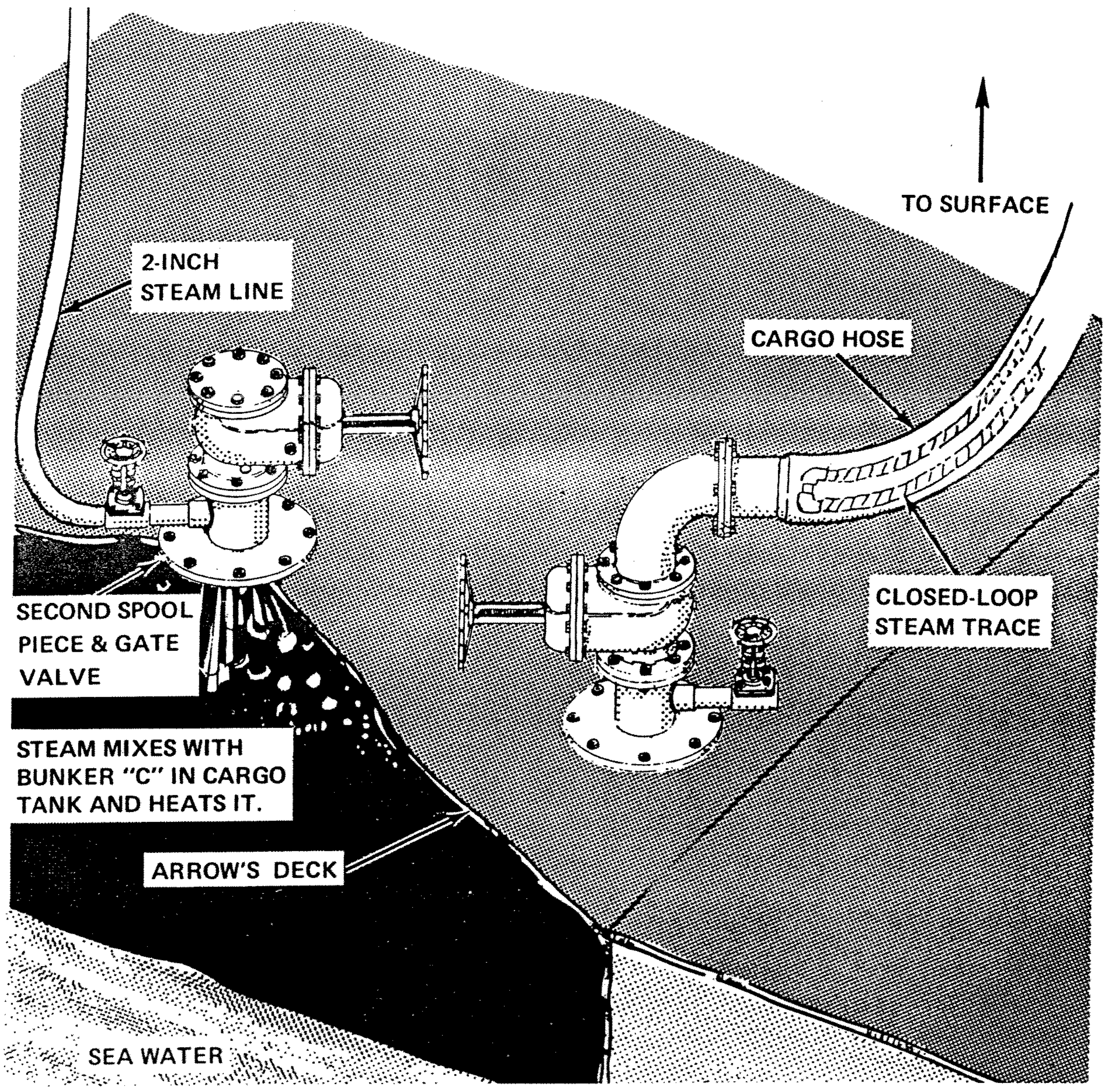


Figure 36. Injecting Steam into ARROW's Cargo Tank.

BACKUP TECHNIQUES FOR HEATING AND LIFTING THE BUNKER "C"

Of the various techniques that were considered for possible use in conjunction with or as replacements for the primary method, four were actually used. Two were techniques for introducing additional steam to heat the Bunker "C" and were used in conjunction with the primary method. Two were airlift techniques in which an airlift was used as the prime mover for lifting the oil, replacing the steam driven salvage pump for this purpose.

The techniques were as follows:

- Injecting steam into the ARROW's cargo tank
- Injecting steam into the spool piece
- Inserting an airlift near the bottom of the suction hose
- Inserting an airlift near the top of the suction hose

INJECTING STEAM INTO THE ARROW's CARGO TANK

In the early stages of preparations for pumping, it was anticipated that waste oil aboard the IRVING WHALE would be pumped down to the wreck to heat the Bunker "C." With this purpose in mind, two hot taps were made on tank 8C, the first target of oil recovery operations. When the idea for using oil as a heat source was abandoned, pumping operations proceeded using just one of these two taps. On the second day of pumping, a 2-inch steam line was attached to the fitting on the side of the second piece and steam injected into the ARROW's cargo tank (figure 36). Five of the 13 spool pieces used in the operation had been constructed with this fitting for backup use in injecting steam.

The reasoning for introducing steam in this manner was that it could help to heat the oil and reduce its viscosity in the cargo tank itself before it flowed through the gate valve area. This might be essential in initiating the flow of oil upward to reinforce the flow caused by the pressure differential between the Bunker "C" and the seawater. The results achieved with this technique were inconclusive. The flow of oil doubled to about 75 barrels per hour with a cargo discharge temperature of about 100°F. However, the increased pumping rate was equally as attributable to other improvements in the pumping system as to the injection of additional steam. It appeared likely that much of the heat was dissipated in view of the distance between the two spool pieces which was some 6 to 8 feet.

Pumping from tank 8C was interrupted by the storm in the night of 15–16 March and the salvage force returned to Mulgrave the following day. This technique was not attempted again when pumping resumed on subsequent deployments. The effort to install an additional spool piece on each tank just for the injection of steam did not appear worthwhile in light of the experience with the first attempt and in consideration of the fact that the primary method was producing adequate results.

INJECTING STEAM INTO THE SPOOL PIECE

The technique of injecting steam into the spool piece was similar to that of injecting steam into the ARROW's cargo tank. It was used on tank 9C during the second pumping deployment. It consisted of attaching a 2-inch steam line to the fitting on the side of the spool piece and injecting steam directly into the spool piece. This method (figure 37) was used in conjunction with an open steam trace with straight fitting in the cargo hose.

The salvage master had high hopes for the effectiveness of this technique since it attacked the Bunker "C" directly in the gate valve area. It was postulated that a small increase in temperature in this area could radically lower the viscosity and contribute to a substantial increase in the rate of flow. However, after apparent early success the flow rate continued much as before and it could not be demonstrated that the additional steam produced any effects.

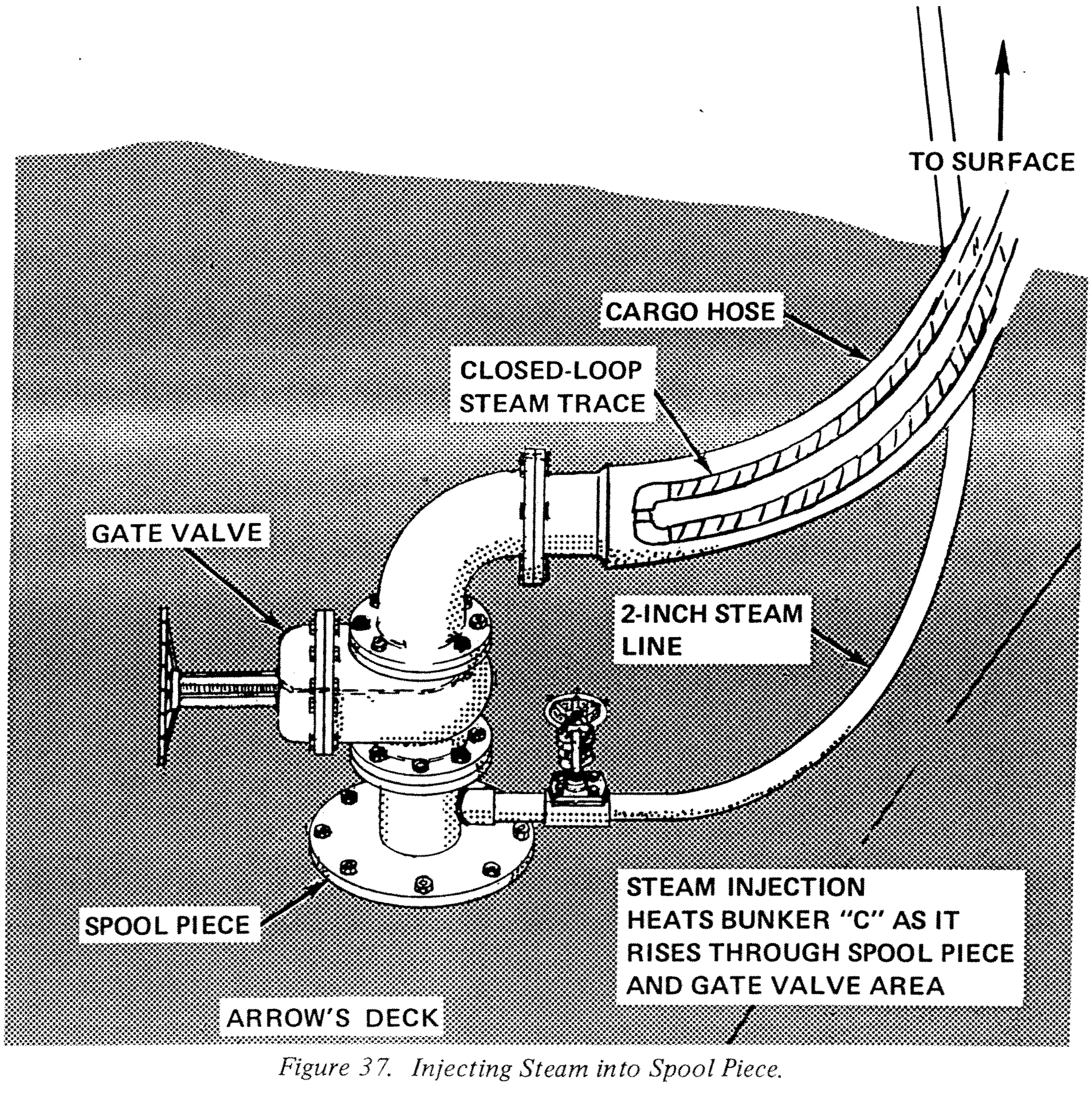


Figure 37. Injecting Steam into Spool Piece.

AIRLIFT AT BOTTOM OF SUCTION HOSE

As far as was known, airlifts had never been employed operationally to lift liquids. However, the tremendous lifting power of airlifts with solid objects was well known to the salvage experts aboard the CURB. Airlifts had been used successfully in eductors, in peri-jet pumps, in mud removal operations, and in the lifting of solid particles. There appeared to be no reason why they would not work in boosting the Bunker "C." CURB personnel advocated their use and an air compressor was procured by the Canadian Department of Transportation and brought aboard the barge to support an airlift effort. The attractiveness of the airlift technique lay in its simplicity where compared to the steam supported pumping system.

It was first decided to inject an airlift at the bottom of the cargo hose in the 90° elbow that connected the cargo hose to the gate valve (figure 38). For this purpose, the fittings were fabricated by CURB personnel. They were installed on tank 7C and used in conjunction with an open steam trace with J-fitting. Air at 100 psi was injected from both sides of the elbow fitting. The basic concept was that air jets could boost the sluggish Bunker "C" across the gate valve area, nullifying the pressure drop that would otherwise occur. The heating effect of the steam trace would then take over to help maintain the suction head as the oil rose to the surface.

Foul weather disrupted operations before the effects of this airlift technique became apparent. The steam consumption for the steam trace was increased. The rate of the flow was disappointingly low. The cause of the difficulty could not be established. It was possible that the air was simply being forced downward, seeking the path of least resistance and working against the flow of oil rather than reinforcing it.

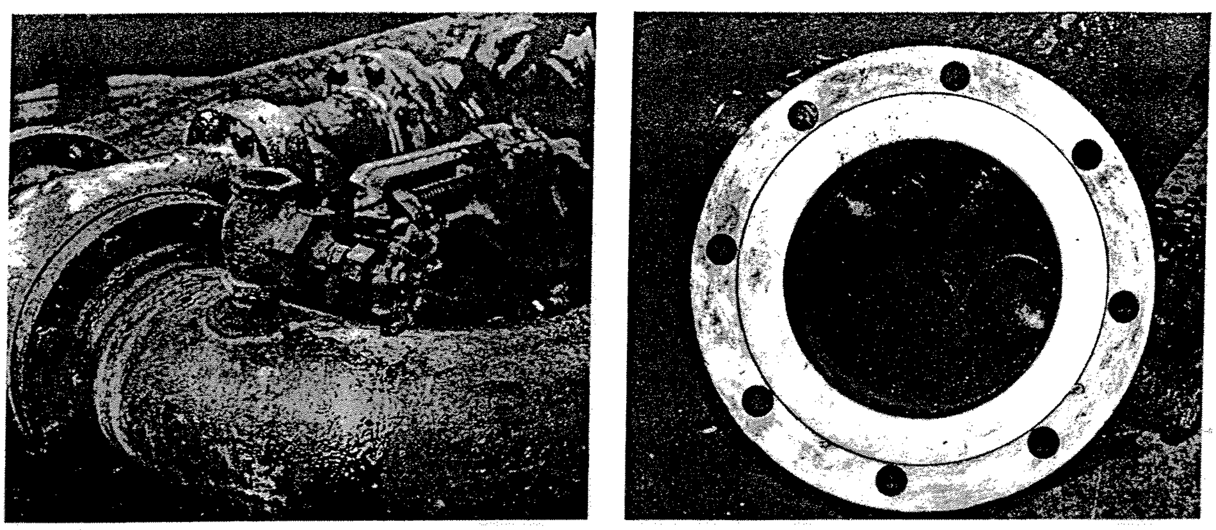


Figure 38. Airlift Fittings in Elbow Connecting Gate Valve to Cargo Hose.

AIRLIFT AT TOP OF SUCTION HOSE

The second airlift technique introduced air jets into the suction hose about 15 feet below the surface. In making up the various hose rigs, CURB personnel normally used a short section

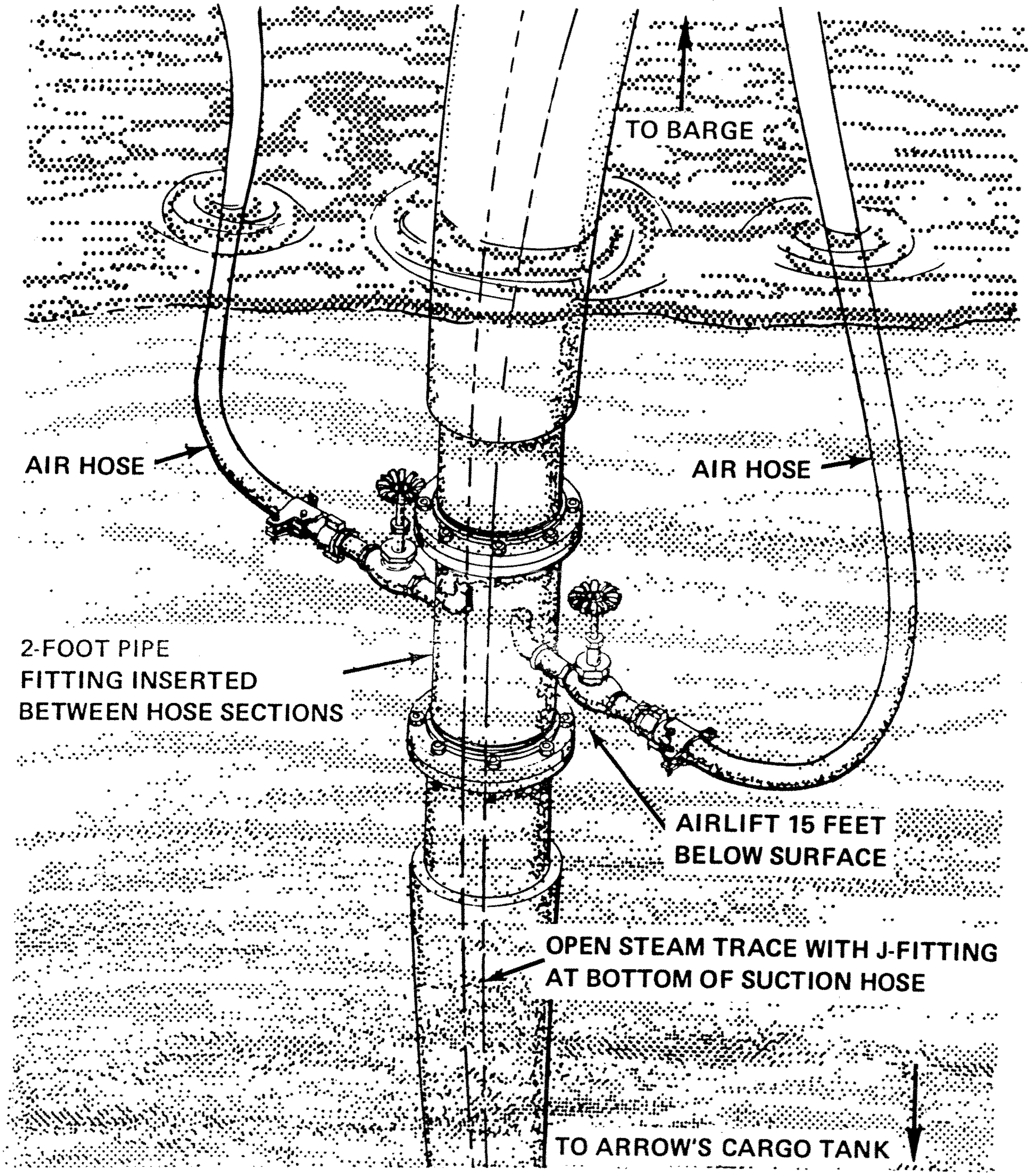


Figure 39. Airlift Fittings at Top of Cargo Hose.

of rigid, metal hose as the connection to the steam pumps aboard the IRVING WHALE. Then, 30-foot sections of 6-inch flexible hose were used to complete the rig. The airlift fittings were made in a 2-foot length of salvage pipe that was inserted between the first two hose sections (figure 39).

This technique was used relatively late in the operation on tank 7S, in conjunction with a single, open steam trace with J-fitting. The discharge rate achieved with this system was comparable to that using the steam-driven pumps as prime mover. The airlift operated for a short period of time in which the boilers were out of commission and maintained a relatively high discharge rate even though the Bunker "C" was cold, since it could not be heated by the steam trace. The technique also worked in spite of difficulties with the air compressor. A maximum of 90 psi of air was being obtained from the compressor whereas the salvage planners had wanted to apply a minimum of 100 psi.

In introducing air jets near the top of the suction hose, salvage planners were relying on the effects of gravity and pressure, reinforced by the heating effect of the steam trace in the cargo hose, to bring the oil to the surface at an appreciable flow rate. The air jets would then give the Bunker "C" the final boost needed to transfer it to the cargo tanks of the IRVING WHALE at an acceptable discharge rate. It was believed that the continuing injection of air into the fuel stream would reinforce the flow rate and increase it as time went on.

CONTAINMENT AND CLEANUP METHODS

SCOPE AND EFFECTS OF POLLUTION

The scope of the containment and cleanup tasks can be appreciated by comparing the ARROW incident with the British experience of the TORREY CANYON. This ship, of course, dwarfed the ARROW in cargo capacity. Its grounding and sinking released 100,000 tons of Kuwait crude oil whereas only 10,000 tons of Bunker "C" were spilled in Chedabucto Bay. The resulting pollution of the Cornish and Brittany coasts was unprecedented. It was caused, however, by no more than 20,000 tons of oil. The remaining cargo of the TORREY CANYON was destroyed or dispersed before it ever reached the shore. It appears that the bulk of the ARROW's spilled cargo came ashore very quickly. There was little time, if any, to treat it in the water. The resulting pollution created fears in the people of Chedabucto Bay that their livelihood was threatened. The task force tried hard to allay these fears by providing accurate information on the consequences of the pollution. The decision to forego the use of detergents and dispersants and to prohibit the deliberate sinking of the oil slicks was critical in this regard. The task force director advised in July 1970, five months after the destruction of the ARROW, that marine fauna and flora below tide were healthy and that fishing and lobstering were normal. The lobster season had gotten underway on schedule in early May; the lobsters had been in hibernation when the oil was spilled and this had helped to protect them. The intertidal zone, however, had been badly affected, with an estimated 25 percent of the clams killed in the early part of the season. The latter did not markedly affect the economy in the area because clams are not economic harvest. The effects of oil pollution on the tourist trade remained to be assessed.

CONTAINMENT MEASURES

The areas principally affected by the oil spill were Petit-de-Grat, Arichat, Janvrin Island, Inhabitants Bay, and the beaches west of Canso (figure 40). The bulk of the oil was deposited along these shorelines. There was also great concern about the probability of the oil infiltrating Lennox Passage and passing through it to contaminate fishing grounds to the north. There were other vital areas that needed protection, including the entrances to the Strait of Canso and Guysborough Harbor. Booms and causeways were the primary containment measures.

Booms

Booms were deployed to protect harbors and fish plants and to trap oil that had already reached wharves, jetties, coves, and inlets. Brush booms made with oil drums and lined with spruce and fir foliage were used extensively, as were commercially constructed rigs that floated from foam buoys. Booms of this type are primarily effective in relatively sheltered areas since waves and tidal currents can defeat them rather easily. Booms were not employed in the open sea to protect exposed beaches as the need for them had largely evaporated by the time countermeasures got underway. Booms for use in open seas are very expensive, requiring elaborate construction to withstand the effects of the sea.

Causeways

Causeways were constructed at four principal locations. The most elaborate were two causeways across Lennox Passage, designed to prevent the ice entrapped oil from moving northward along the Cape Breton coast when the ice broke up in the early spring. These were permanent installations, totaling 1800 feet in length. By coincidence, the people of the area had long desired a causeway so the building of these barriers did not provoke any social problems. Their construction, nevertheless, underwent careful study as causeways can significantly change the ecology of an area by interfering with normal fish movement, radically altering water levels, etc.

A causeway was also constructed on the southern side of the bay, west of Canso, to block oil infiltration along a waterway to Canso Harbor. Other causeways were installed near Janvrin

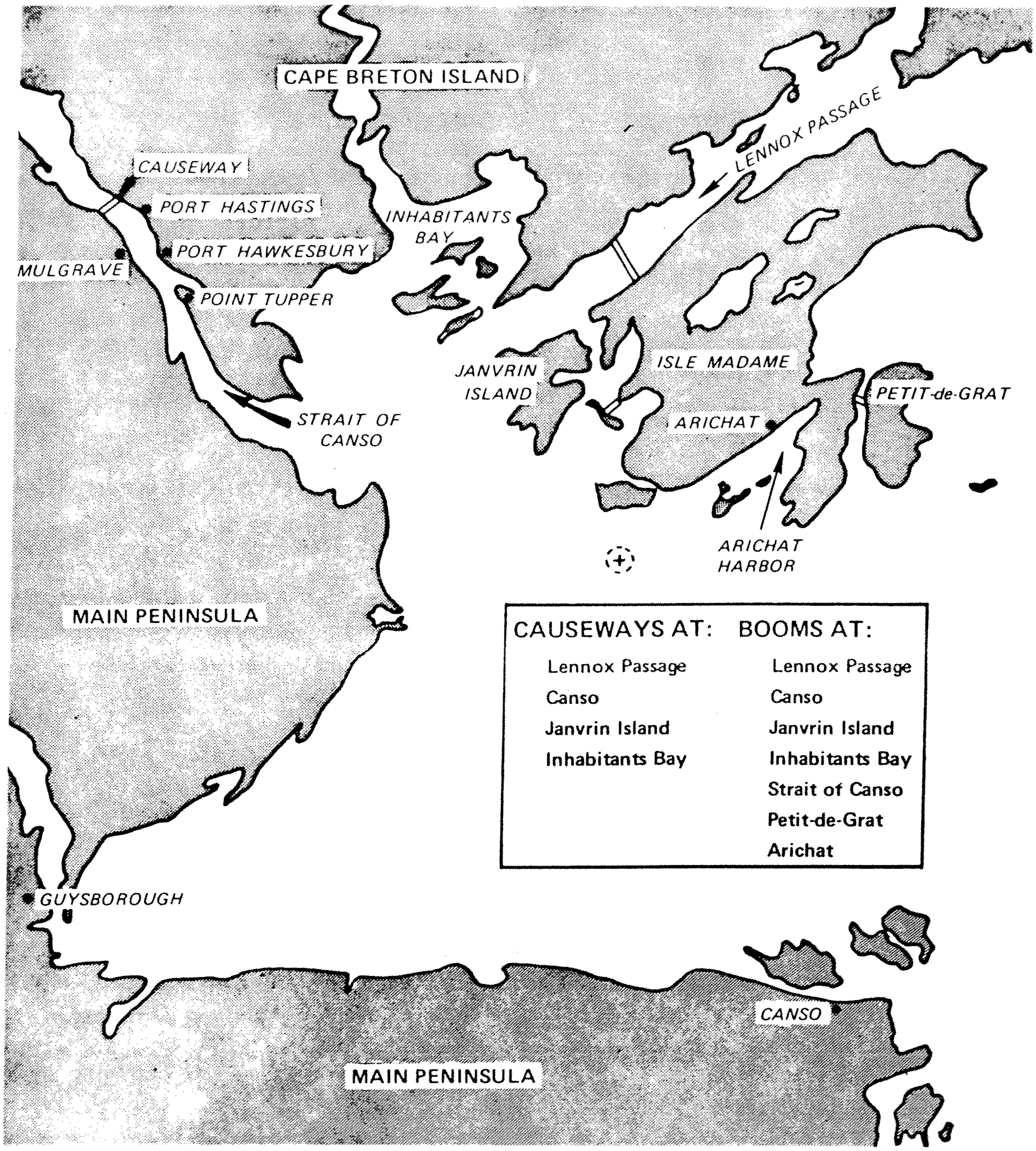
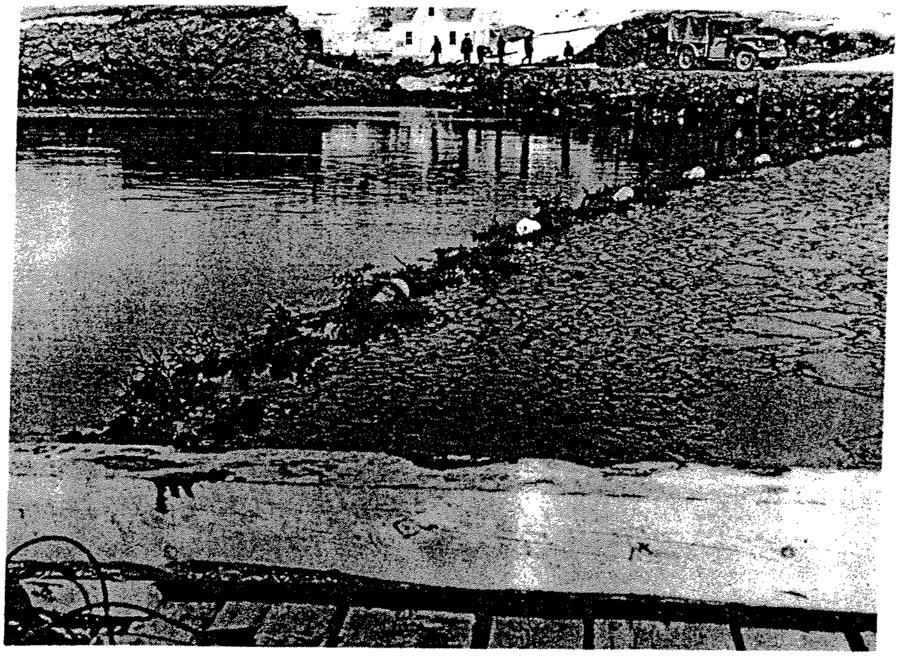


Figure 40. Areas of Causeway Construction and Boom Deployment.

Island and at a river inlet on Inhabitants Bay to block further penetrations of the Bunker "C." These were designed as temporary installations.

Figure 41 shows views of boom emplacement and causeway construction.



Brush boom traps oil between jetty and shoreline.

Causeway protecting Canso area against infiltration of Bunker "C" through coastal waterway.

Figure 41. Views of Boom Emplacement and Causeway Construction.

Other Methods

Other devices for containing the oil included fish nets and metal screening. Fish nets were used principally in conjunction with contingency planning for new spills from the ARROW's hulk. It was believed that fine mesh netting, such as used for herring or shrimp fishing, might be able to contain the oil long enough to permit burning or pumping from the surface of the sea. However, the expense of fish nets limited their use as general purpose containment devices.

BURNING AGENTS AND DETERGENTS

Corning SEABEADS Tests

SEABEADS are ¼-inch-diameter glass modules developed by the Pittsburgh Corning Glass Company. They depend upon the "wick" principle to burn oil on the surface of the water. The beads are presumed to have an insulating effect which prevents the water from extinguishing the fires. The pumice-like glass beads had proven effective in other oil spills by acting as a wick for the heavy oil.

A shoreside test was conducted on 9 February by Pittsburgh Corning Glass representatives, followed by a test at sea on 13 February. RCN divers and explosive ordnance disposal personnel participated in these experiments. Although the shoreside test was successful, the sea test was not. Winds kept blowing out the fire. The Bunker "C" proved easy to ignite as long as the beads were adequately spread and then primed with benzine. Difficulty in achieving the initial bead coverage and benzine priming also contributed to the unsuccessful trial.

The beads appeared to be effective against fresh bunker. Existing stocks of the material and the dispersing machine were retained for possible future use in an emergency; no further efforts were made to burn the oil with this agent.

KONTAX Experiments

KONTAX, a very expensive German product, was available in limited supplies for use as a burning agent. It was the only known commercial material capable of readily firing fresh Bunker "C." As in the case of other burning agents, the longer the period before burning is attempted, the less chance there is of achieving combustion. It was planned, therefore, that if enough KONTAX were to become available, it would be used in executing the task force's contingency plan as soon as possible after a spill occurred, and not delayed until the oil was at sea.

The KONTAX was packaged in 4-pound plastic bags that had to be punctured before release. The task force scientific advisor, after experiments in its application, reported that helicopter distribution of the material was impractical and recommended dispensing it from the ramp of an LCM for use close to the shore. It was concluded that KONTAX was only marginally effective on fresh Bunker "C" but that it appeared promising for use on lower viscosity fuels. Its effectiveness ashore on aging and weathered Bunker "C" was apparently minimal.

The task force staff estimated that available resources would permit dispersal of approximately 2 tons of KONTAX per hour. Planning was initiated to obtain a stockpile of 2 tons on consignment to be returned to the manufacturer if not used.

Application of COREXIT

COREXIT 8886 is a water-based emulsifier. The Imperial Oil Company brought in 400 barrels of this material. The object in its application is to achieve a highly diluted oil-in-water emulsion in which the oil is dispersed in extremely small droplets coated with an emulsifier that prevents the particles from coalescing into large globules or patches. Emulsifiers mixed with solvents (detergents) had been widely used in many previous spillages, particularly in the TORREY CANYON incident. There was hope, initially, that similar procedures could be applied in Chedabucto Bay even though the Bunker "C" was of unusually high viscosity. The ARROW's cargo had come from Venezuela. The high values of asphaltenes found in Venezuelan oils increase the rates of spreading and emulsification.

The purpose of applying detergents on the open sea is to disperse the spilled oil before it reaches the shore. The natural action of the sea also disperses the oil, reducing the amount of detergent required the longer treatment is delayed. Because detergents are expensive and can poison marine life above a certain level of concentration, delay may be warranted if the threat of coastal pollutions is not increased. The task force staff estimated that over a million dollars might be required to apply sufficient COREXIT to cope with a spill of about 8000 tons of Bunker "C" remaining in the wreck.

Small quantities of COREXIT were sprayed from light aircraft very early in the operation. The results were inconclusive. Its use was not attempted again in view of the task force decision against the application of detergents within the bay or closer than 5 miles offshore outside the bay. Quantities on hand were retained for possible use in future contingencies.

CLEANUP METHODS

Absorbents

Peat moss emerged as the most effective absorbent available in reasonably large quantities. A team of scientists from the Canadian University of Sherbrooke arrived in the area in late February. They advised that laboratory experiments had indicated that peat moss would absorb up to eight times its own weight of floating Bunker "C" oil. They also had valuable innovations to make regarding the use of fencing and screening devices in conjunction with the peat moss to contain the oil.

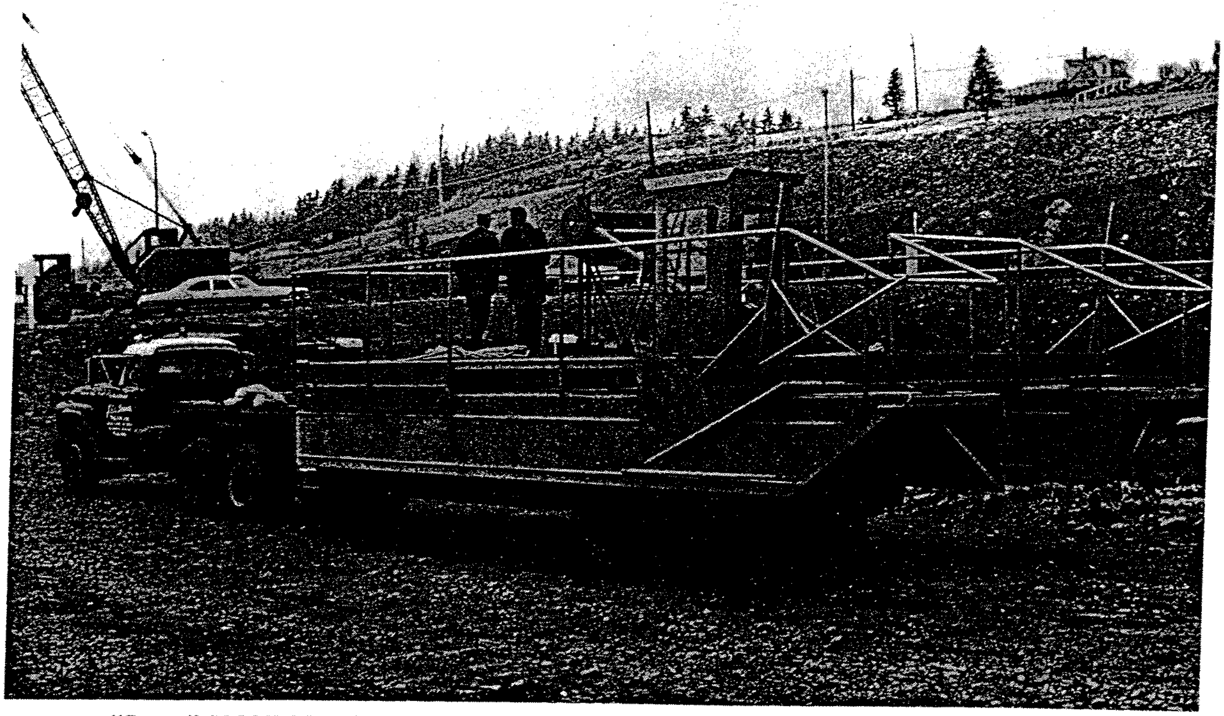
Large quantities of peat moss were procured and placed aboard the IRVING WHALE for use in contingencies. A dispersing machine was to discharge the mulch over the side and spread it from rubber boats. When the accidental spill from the ARROW's bunker occurred, personnel from the diving tender YMT-12 helped to spread the peat moss (figure 42). The mulch was also used extensively in cleanup operations ashore to help make the Bunker "C" more manageable. A related characteristic of peat moss, although one that could not be applied in these circumstances, is that it apparently can be burned easily by use of gasoline or other suitable starters.

Figure 42. RCN Divers Spreading Peat Moss on Oil.

SLICK LICKER Machines

The SLICK LICKER is a machine developed by the Canadian Defense Research Establishment Pacific. Four of these machines were brought to the operational area in late March and used extensively to pick up oil remnants close to the shore. Three were portable devices that could be mounted in an LCM-type craft. The fourth, a larger, more elaborate model, dubbed the "super" SLICK LICKER, was designed for permanent mounting in a catamaran-type platform. Both versions are pictured in figure 43.

SLICK LICKER lapping up Bunker "C" residue from lagoon in Inhabitants Bay.



"Super" SLICK LICKER being transported to employment site. Note catamaran-type hull.

Figure 43. Views of SLICK LICKER Machines.

The SLICK LICKER machines have a formidable capability to literally lick up or lap the oil from the surface and to draw it into the draft by a conveyor belt where it can be discharged into drums. Like most forms of mechanical removal, it is slow work, but it does pick up the oil. The basic limitation of such machines is their inability to store large quantities of the recovered oil. The task force used the SLICK LICKER to remove oil from strategic and particularly sensitive locations throughout the bay.

There are apparently numerous skimming, scooping, or sucking devices of this type in operation or under development throughout the world. Their use is for the most part, confined to calm water areas, such as ports and harbors. For example, in Baltimore Harbor, a shallow draft boat is used that has a roller mounted on its bow. The roller dips into the water where it is preferentially wet by the oil film. On rotation, the roller is scrapped off by the roller inboard.

Archimedes Screw Pump

There were many patches of Bunker "C" still adrift in the bay and larger quantities trapped in coves and inlets or contained by booms. Attempts were made to pick up these remnants with an Archimedes Screw Pump.

This device consisted of a rotating, threaded shaft inside an 8-inch-diameter cylinder. It was designed to be lowered into the water and to suck up oil on the surface through centrifugal action. This mechanism proved incapable of picking up any significant quantities of the "goo" or "goop" as the dirty, stubborn mixture of bunker, water, sand, seaweed, and other materials had come to be called by the military and civilian workers trying to clean it up.

Heavy Equipment Operations

All applicable types of earth moving equipment were committed to the beach clearing effort. The oil on the beaches was treated with dry sawdust, peat moss, straw, and other available absorbents that facilitated picking it up. Vehicles capable of dispensing steam and high pressure water were used to clean piers and jetties. Commercial pumping trucks, normally used for cleaning septic tanks, were engaged to pump oil standing close to shore and trapped by booms.

Of the approximately 75 miles of shoreline infested with oil in varying amounts, a total of perhaps 30 miles were in beach areas. This is where the cleanup efforts were concentrated. It seemed likely that much of the remaining shoreline would never be cleaned since many areas were inaccessible to heavy equipment. Whatever cleaning was to be done would only be accomplished over a long period of time by the processes of nature.

EXECUTION OF CONTINGENCY PLAN

The need to execute the task force contingency plan arose on 25 March when divers accidentally blew open the tank top cover on the ARROW's bunker. An estimated 300 tons of fuel oil escaped. The task force committed the YMT-12 to track the resulting oil slicks. Army troops were helicoptered from outside the operational area to Arichat to stand by for possible cleanup tasks. Fishing boats with fish nets for use as containers were deployed to the scene.

The wind changed a few hours after the spill and blew the oil out to sea. Tracking the spill in darkness proved impractical, revealing the need for iridescent materials to mark the passage of the spill. The problem of detecting and tracking possible spills had been given much study by the task force. The communications in the fishing boats were also inadequate to maintain effective contact with the YMT-12 during the chase.

MEASURES TO ASSIST THE POPULATION

Fouling of fish nets was one of the most immediate and obvious effects of the oil spill. Fishermen throughout the bay area began to complain of dirtied nets and were fearful of the consequences on their catches. This was no small matter. Certain nets, such as those used for herring, sometimes cost up to $25,000. All of them were vital to the commercial interests of the bay's fishermen.

Acting on a suggestion forwarded by a citizen of Truro, Nova Scotia who was in the dry cleaning business, the task force devised a laundromat that effectively cleaned the fouled fishnets. The laundromat, controlled by the Fisheries Department, operated on a regular schedule, responding to the fishermen's needs. The good will gained by this effort was of far greater value to the task force than the expense required to develop and operate the facility. The laundromat was also put to practical use at the end of the salvage operation in cleaning oil-saturated mooring lines.

Great care was taken to explain the intentions and projects of the task force to the people of the bay. They were understandably upset and alarmed about the situation. The need for a public information effort was brought home early in the cleanup operation when a county road engineer decided that spraying dusty gravel roads with recovered Bunker "C" would be an efficient way of disposing of some of the oil. As Army trucks were oiling the roads, the local citizens became enraged. Assembling in the area they locked arms and presented a human barricade to block further spraying. After discussing the problem with the people, the task force had a front end loader pick up the Bunker "C" and gravel, regrade the road, and place fresh clean gravel on it.

There are fish plants at Petit-de-Grat, Canso, and Arichat where fish meal is produced by grinding scrap fish. The spilled oil contaminated their inlet water systems, causing great alarm. The task force was successful in designing filters and strainers that effectively stopped the contamination. Undertakings of this type did much to reassure the population that everything possible was being done to help them.

LESSONS LEARNED

1. The factor of time is critical in salvage operations, particularly at the outset when immediate action is required to prevent futher deterioration of the situation. The longer the time consumed in the conduct of operations, the greater is the likelihood that weather and other factors will disrupt and delay the effort.

2. There is a clear need for oil tankers, Naval as well as commercial, to be fitted with deck access connections and, possibly, hull connections to each of their cargo and fuel tanks. Connections, such as those made to the ARROW's tanks by the YMT-12's divers, would be simple and inexpensive to make under shipyard conditions and easy to maintain thereafter. Had such fittings been previously installed on the ARROW, it is probable that the lightering operation could have been started much sooner and concluded much more quickly. It would appear that this is a small and prudent insurance investment that would accelerate similar lightering operations in the future.

3. The potential of steam pumping systems appears very limited when compared with that of electric submersible pumps currently under development or with that of airlift methods. The key factor in comparing the potential of these systems is the scope and variety of the logistic effort required to properly support them. The simplicity of the airlift concept and its wide applicability suggest that it should be given priority in research and development efforts.

4. Although their use was rejected in this operation, cofferdams also are worthy of further study and development in view of their potential for rapid debunkering of large quantities of oil. The application of rigid materials, such as piping, is perhaps confined to calm areas; but there appears to be no technical obstacle to the use of large diameter flexible materials that could more easily withstand difficult sea conditions.

5. A heating capability should be an integral feature in the development of improved pumping or airlift systems. It is clear that the effort made to heat the ARROW's cargo was worthwhile even though its effects could not be accurately measured. Electrical immersion heaters for tank penetrations and resistance heaters built into suction hoses should be carefully considered. The insertion of electrical strip heaters into any cargo tank access fittings that may be installed would appear to be a practical means of ensuring an adequate supply of heat in this particularly critical area.

6. It is commonly accepted that the best way to dispose of the cargo in a sunken tanker is to pump it up into a receiving vessel. This may be true given the current state of technology in controlling oil pollution. The problem, however, is to neutralize the pollution potential of the cargo. Concentration on salvage techniques should not obscure the necessity and value of examining means, other than salvage, of solving the problem. It may be, for example, that additional research effort in the chemistry of fuel oils can produce efficient gelling agents that could eliminate the need for a salvage effort.

7. The ARROW operation, as a whole, demonstrated the need for extensive governmental intervention and participation in the overall effort to control the pollution and mitigate its effects. It seems clear that effective reaction to a massive pollution incident is beyond the capabilities of the private sector. The scope and variety of resources that must be marshaled, coordinated, and applied require a staff effort that governmental agencies are best equipped to conduct.

8. The planning conducted for this undertaking was essentially ad hoc, relying almost exclusively on the operational experience of various key leaders and participants. There was no other alternative available. It is highly desirable that documentation of available equipment, techniques, and material for dealing with oil pollution incidents be prepared and widely distributed. Such documentation could do much to assist those with operational responsibility to determine the best available means for employment in future incidents.

9. Stockpiling of equipment and material in locations readily accessible to a task force and provisions for deploying it in appropriate contingency plans would appear to be prerequisite to immediate, effective response to future disasters. With few exceptions such equipment is air transportable and contingency planning should provide for this transportation means.

10. The ARROW operation, particularly in its pollution control and cleanup phases, demonstrated that a team of scientists on the task force staff can be invaluable in coordinating scientific advice in response to the great variety of scientific and technical problems that inevitably arise. It also demonstrated that a fully developed public information effort is essential to ensure that the work of salvage and pollution control can go forward with the cooperation and support of the affected population.

11. Future involvement of the U.S. Navy in pollution control operations resulting from damaged or sunken tankers appears highly probable. The report on the TORREY CANYON noted that in the period 1964–1967, 91 tankers were stranded and 238 involved in collisions in various parts of the world, an average of two potentially serious accidents a week. A Navy tanker could be stricken, requiring the Navy to assume full responsibility at sea and on shore. Various circumstances could oblige the Navy to participate, partially or fully, in sea and shore efforts in response to a commercial tanker accident. This probability indicates the need for a review of current programs to ensure readiness of personnel and equipment to undertake such operations.

ARROW NAVSHIPS 0994—008—1010