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Recovery Of Low-Level Radioactive Waste Packages From Deep-Ocean Disposal Sites

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RECOVERY OF LOW-LEVEL RADIOACTIVE WASTE PACKAGES FROM DEEP-OCEAN DISPOSAL SITES

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FOREWORD

In 1972 the Congress enacted Public Law 92-532, the Marine Protection, Research and Sanctuaries Act, which authorized the Environmental Protection Agency (EPA) to regulate any future ocean disposal of waste materials, including low-level radioactive waste (LLW).

Accordingly, since 1974, the EPA Office of Radiation Programs (ORP) has conducted studies at Atlantic and Pacific ocean sites used by the U.S. from the 1940's to the late 1960's for disposal of LLW. The studies were conducted to: determine whether current technologies could be applied to assessing the fate of radioactive wastes disposed in the past, by locating and evaluating the condition of LLW packages and by measuring radioactivity in samples of sediment and biota to determine whether the marine environment had been adversely affected, and, if so, whether such effects posed any detrimental health effects to man. The studies were also designed to provide information for developing effective controls to protect man and the marine environment from any future ocean disposal of LLW.

ORP successfully located radioactive waste packages in the formerly used LLW disposal sites and then initiated an extensive monitoring program to examine geological, biological, physical and chemical characteristics of these site, as well as to determine the presence and distribution of radionuclides in and near the sites. ORP has also evaluated the performance of past packaging techniques and materials by recovering LLW packages from three deep-ocean disposal sites.

The first LLW package was recovered from the Atlantic 2800-meter disposal site in 1976. Additional packages were recovered from the Pacific (Farallon Islands) 900-meter and Atlantic 3800-meter sites in 1977 and 1978. This report describes the techniques used to recover the three LLW packages.

The Agency invites all readers of this report to send comments or suggestions to Mr. Martin P. Halper, Director, Analysis and Support Division (ANR-461), Office of Radiation Programs, U.S. Environmental Protection Agency, Washington, DC 20460.

Richard J. Guimond, Director
Office of Radiation Programs

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1 INTRODUCTION

The former U.S. Atomic Energy Commission (AEC) licensed the ocean disposal of low-level radioactive waste (LLW) beginning in 1946. From that time until 1962, when land disposal was approved, LLW was routinely embedded in concrete contained in steel drums and dumped primarily at three AEC-designated Atlantic and Pacific ocean disposal sites. The depths of water at these sites ranged from approximately 900 to 3800 meters. Approximately 75,000 LLW packages were disposed of in this manner before ocean disposal was terminated in 1970 following the recommendations of the Federal Council on Environmental Quality in a report to the President.

Increased environmental concern about using the oceans for disposal of LLW is evident in domestic and international research activities, discussions of international scientific organizations, U.S. legislation, and in the activities of the U.S. Environmental Protection Agency (EPA) which regulates U.S. ocean disposal of all types of waste materials. As a first step in developing effective regulatory controls, the EPA initiated a program to determine the effectiveness of past LLW disposal techniques. EPA conducted surveys in 1974 and 1975 of Atlantic and Pacific ocean sites that were used previously for LLW disposal. Manned and unmanned submersibles were used to assess the physical condition of LLW containers and the near-field distribution of any released wastes.

Early controls on the packaging of LLW were aimed at ensuring that the packages reached the ocean bottom relatively intact; but standardization of size, shape and internal configuration was not a requirement. As a result, the disposal packages were found to vary in size and weight; the majority being between 55 and 80 gallons with weights in water ranging from 550 to 1400 pounds (250 to 650 Kg). To ensure sinking, the AEC required that the packages have a minimum weight of 550 pounds. Internal configurations frequently included an inner container housing the waste materials which was surrounded by concrete that filled the remainder of the inside of a steel drum. These waste packages were, in fact, pressure vessels with concrete walls and end caps and many configured in this manner reached the ocean bottom in a distorted condition as a result of implosion due to increasing hydrostatic pressure acting upon the waste container as it descended.

The EPA site surveys in 1974 and 1975 pointed to the need for further information, The EPA site surveys in 1974 and 1975 pointed to the need for further information, particularly in determining more precisely the contents and packaging techniques used in past disposal operations. In 1976, the Woods Hole Oceanographic Institution (WHOI) was awarded a contract from EPA to develop a method for recovering selected LLW packages from ocean sites previously used for disposal of LLW. Recovery would allow for more detailed study of waste packages and their contents after prolonged exposure in the marine environment. The recovery technique developed by WHOI was used to successfully retrieve three LLW packages from formerly used disposal sites in the ocean. In July 1976, an 80-gallon waste drum was recovered from the Atlantic Ocean 2800 meters LLW disposal site. Another drum was recovered from the Pacific Ocean 900 meter LLW disposal site, near the Farallon Islands, in October 1977, and a third drum was recovered from the Atlantic Ocean 3800 meter LLW disposal site in June 1978.

2 DISCUSSION OF RECOVERY PROBLEMS

Recovery of a one-half-ton object from the deep ocean is not a trivial undertaking in the best of conditions. There are four major categories of associated tasks to accomplish recovery: 1) object location (navigation); 2) attachment of lift and recovery equipment; 3) lift to the surface; and 4) surface handling of the recovered object. For LLW package retrievals, the nature of the objects to be recovered added to the normal difficulties associated with each of these tasks since special handling and contamination prevention procedures had to be instituted.

2.1 Navigation

U.S. ocean disposal of LLW was conducted at designated sites by licensed contractors. Site designation and licensing were carried out by the former U.S. AEC. LLW disposal packages were required to be labelled with a reference number and an indication of the contents. Disposal records were to be maintained for each site. The records were to provide the location and date of LLW disposals, plus the quantity and reference number for each disposal package.

Using disposal records, the AEC conducted towed-camera disposal site surveys between 1957 and 1961 at some of the sites that had previously been designated to receive LLW. No photographs of packaged LLW were found in the Atlantic or Pacific sites surveyed. The most likely cause for such a discrepancy is that navigational errors occurred at the time of disposal or, later, during the site surveys. LLW packages were, however, successfully located during EPA surveys of AEC-designated disposal sites in 1974 and 1975.

2.2 Lift and Recovery Equipment Attachment

The waste packages of interest were not designed to be recovered. Although basically similar, differences in construction and degree of deterioration made the design of a suitable recovery device a challenging project.

The disposal packages were usually 55-gallon oil drums. In some cases, however, the length of the package was increased by welding half of one 55-gallon drum to the top of another. The weight of the packages varied, depending on size and contents, but calculations indicated that a large drum totally filled with concrete would weigh 1400 pounds (650 kg). Therefore, 2000 pounds (907 kg) was selected as a reasonable maximum for design purposes. Some disposal packages had attached lifting bails (handles), but they were considered to be unreliable due to deterioration from lengthy submergence. For the same reason, an attachment device for lifting could not rely on the usual details of 55-gallon drum design, such as the end chimes and the ridges around its middle. A device was required which could provide a reliable link between a lift line and a heavy cylinder, partially submerged in sediments and in any possible orientation, without relying on any characteristic of the cylinder other than its general shape. This device would also need to be strong enough to withstand handling by the manipulating arm of a submersible.

2.3 Lift Method

Two methods were available for returning a heavy object from the sea floor to the surface: 1) attachment of a floatation package, and 2) direct lift by using a surface winch. In recovering a LLW package, the capability to control lift speed was considered important since too rapid an ascent might cause the drum to rupture because entrapped water might not be allowed adequate time for pressure equalization to occur. Conversely, a flotation package, designed for slow ascent, could be subjected to considerable horizontal displacement (drift) from the surface recovery ship due to transport by ocean currents as it ascended. Locating a LLW container on the surface that was recovered by the flotation technique could pose an added difficulty to the recovery operation. Direct lifting of the package from the sea floor, using a surface winch, would solve both of these problems, but at a cost of increased operational complexity.

2.4 Surface Handling

Generally, successful handling and recovery of heavy objects at sea requires that the object pass through the air-sea interface as quickly as possible. Potentially hazardous waste packages, however, cannot simply be pulled from the water and placed on the ship's deck without carefully considered safety measures. These measures must include a means for containing any material that might break off or seep from the drum during recovery and once it is onboard. This would likely result in holding a LLW drum out over the ships's side, clear of the water and the deck, for a period of time. This would prolong the time during which maximum stresses would be placed on the lifting devices/equipment, due to ship motions especially in other than calm seas.

3 PRELIMINARY EQUIPMENT INVESTIGATIONS

Early in 1976, the Deep Submergence Engineering and Operations Group (the ALVIN submersible Group) of the WHOI entered into a contract with EPA for the design and demonstration of a system capable of recovering LLW packages from ocean disposal sites. Various retrieval methods were considered during preparation of the initial proposal, but all centered upon using the manned submersible ALVIN to locate a suitable LLW package and attaching a lifting device to recover it. Four methods for performing the actual lift and recovery were investigated and are outlined in the following subsections.

3.1 Constant-Buoyancy Lift Package

A constant-volume flotation package would be attached to the LLW package by the submersible. The package would have over 1400 pounds (650 kg) of buoyancy for use in lifting an 80-gallon drum. Thus, a releasable ballast weight would be required to allow the flotation package to free fall or be carried to the sea bottom. Two flotation materials were considered: syntactic foam and glass spheres. Both had the advantage of low compressibility and, therefore, would provide buoyancy forces which would be essentially constant with depth.

Using a syntactic foam with a density of 36 pounds/cubic foot (576 kg/cubic meter) required a recovery device with a volume of approximately 70 cubic feet (2 cubic meters) with an air weight of 2500 pounds (1135 kg) plus the weight of a suitable frame to hold it all together. A descent weight of approximately 2000 pounds (910 kg) would be required.

The largest readily available glass spheres, suitable for deep-ocean usage, were 17 inches (43.2 cm) in diameter. One would provide 52 pounds (23.6 kg) of buoyancy. Approximately 30 would be needed to lift an 80-gallon LLW package, and approximately 2000 pounds (910 kg) of releasable ballast would also be required.

Flotation devices constructed by using syntactic foam or glass spheres could be launched from a reasonably equipped support ship and allowed to free fall to the bottom, hopefully landing near the LLW package to be recovered. Attachment to the LLW drum and release of the ballast weight on the flotation device would then be done by the submersible, which would also move the package closer to the drum if required.

We found that multiple problems existed for this method. The flotation devices were large, making surface and submerged handling difficult. The buoyancy was fixed in advance, thus the speed of ascent during recovery could not be closely controlled without knowing the weight of the LLW package in advance. Special hardware additions, such as strobe lights and radio beacons, would be needed so that the flotation device and LLW package could be located on reaching the sea surface. Finally, and perhaps most importantly, when the submersible released the flotation device ballast weight, a possibility (although remote) existed that the LLW package could fall out of the flotation device and onto the submersible. Since none of these problems were unsolvable, this method was considered to be realistic for use in recovering LLW packages.

3.2 Variable-Volume Lift Devices

These include lift bags incorporating gas generators to provide flotation only when it is needed. They have the advantage of decreased size and mass compared to fixed flotation devices. Thus, surface and submerged handling would be less of a problem. At the time of the proposed work, experiments had been conducted by the U.S. Navy with two methods for high pressure gas generation: the reaction of sea water with lithium hydroxide, and the decomposition of hydrazine fuel. Both of these methods had been field tested, but not in a size adequate to yield enough gas for LLW package recoveries.

The other problems associated with fixed flotation packages (e.g. ascent speed control, surface location difficulties, and danger to the submersible during recovery) also existed for variable-volume lift designs. The problems could be solved, but due to the development effort required to obtain a safe recovery device of suitable buoyancy, this method was not proposed for recovering the LLW packages.

3.3 Surface Ship Direct Lift

At first consideration, this method appeared to be the most straightforward solution. A surface ship would lower a weighted lift cable to the bottom and the submersible would attach the lift cable to a lifting device on the LLW package. A major problem, however, was that the submersible would not be able to move the end of the lowered cable because of its weight, thus the cable end would have to be lowered close to the LLW package by the surface ship. This type of operation has been conducted by WHOI previously. Based on that experience, the following procedures were proposed: 1) bottom-moored acoustic transponders would be emplaced in the disposal area to provide reference points for an accurate bottom-tracking navigation survey; 2) the ALVIN would then conduct a sea bottom navigation survey of the disposal area, utilizing the ALNAV long baseline acoustic navigation system (see Appendix), and identify a suitable LLW package for recovery (the exact position of the container would be established from the bottom navigational data); 3) after ALVIN surfaced, the lift cable, with a releasable weight and an acoustic transponder "marker" attached to the end, would be lowered to within a few hundred meters of the bottom; 4) the surface ship would then maneuver the end of the lift cable into the correct position for recovery by tracking the "marker" as it moved within the navigational network established during the earlier ALVIN dives; 5) additional lift cable would then be paid out to allow its weighted and marked end to rest on the bottom near the target LLW package; and 6) ALVIN would dive again to attach a lifting device to the LLW package, to connect this device to the lift cable with a suitable tag line, and to release the lift cable weight.

None of the problems associated with the flotation package concepts were present with this method, but there was a potential submersible safety hazard. During the attachment phase of the operation (# 6, above), ALVIN would be working directly beneath a long, heavy cable leading to the surface ship. If the cable parted, it could very well fall on the submersible - trapping it on the sea floor. The proposed solution was to use a lift cable with minimal water weight, such as polypropylene or Kevlar line.

3.4 Submersible Direct Lift

This concept was not included in the original proposal. With this method, a LLW package could be recovered ‘directly’ by using a tag line attached to a submersible. It is a simpler recovery operation than the others proposed, but it requires that the submersible have no less than a 1400-pound (650 kg) payload capacity - more than available with ALVIN at this time.

4 1976 RECOVERY, ATLANTIC OCEAN 2800-METER LLW DISPOSAL SITE

4.1 Equipment Design and Preparations

4.1.1 General Considerations

In July 1976, EPA and WHOI scientists conducted the first recovery of a LLW package from a deep-ocean disposal site. The site had an area of 100 square miles (256 km^2) and was centered at 38°30'N and 72°06'W, with an average water depth of 2800 meters (Figure 1). The surface ship direct lift recovery concept was selected as the method of retrieval. The potential safety problem (submersible working directly under a heavy lift cable) was resolved by using a 0.445-inch (1.13 cm) diameter, 19 x 7 strand Kevlar cable with a breaking strength of 10,000 pounds (4500 kg) and a water weight of 0.02 pounds per foot (30 g/m). Because of the low stretch characteristics of the Kevlar line, a standard trawl winch could be used during recovery rather than a traction machine, which would likely be needed if other lightweight synthetic lines were used.

The ALVIN's support ship, R/V LULU, did not have a long-lift capability, so the R/V CAPE HENLOPEN, operated by the College of Marine Studies at the University of Delaware, was used as a second support vessel for this operation. The CAPE HENLOPEN was well suited for this recovery because of its medium size, making it easily maneuverable, its reasonably large and clear aft deck work area, and its standard trawl winch was suitable for the Kevlar line.

4.1.2 Lift Line Attachment Devices

Design of a lift line attachment device was of critical importance to this recovery operation. All proposed concepts were again reviewed and deemed feasible, but it was concluded that they all had a common fault - dependency on the waste container's strength (integrity) to ensure a secure lifting attachment. This was considered risky since the condition of the drum to be recovered was unknown. As a result, it was decided to construct two attachment devices: a mechanical cam-lock "grabber" (Figure 2) requiring a reasonably intact and solid LLW drum, and a wire rope harness assembly (Figure 3) which required only that the drum not fall apart under its own weight.

The mechanical cam-lock grabber was intended for use on a partially buried drum lying horizontally. The cam locks were designed to grip the package close to its horizontal midline to avoid possible actuation interference from the sediment. Since the strength of the drum could not be trusted, the cams were only intended to assist in tipping the drum on its end to place its weight on a lift platform. The chain bridle to which the lift line

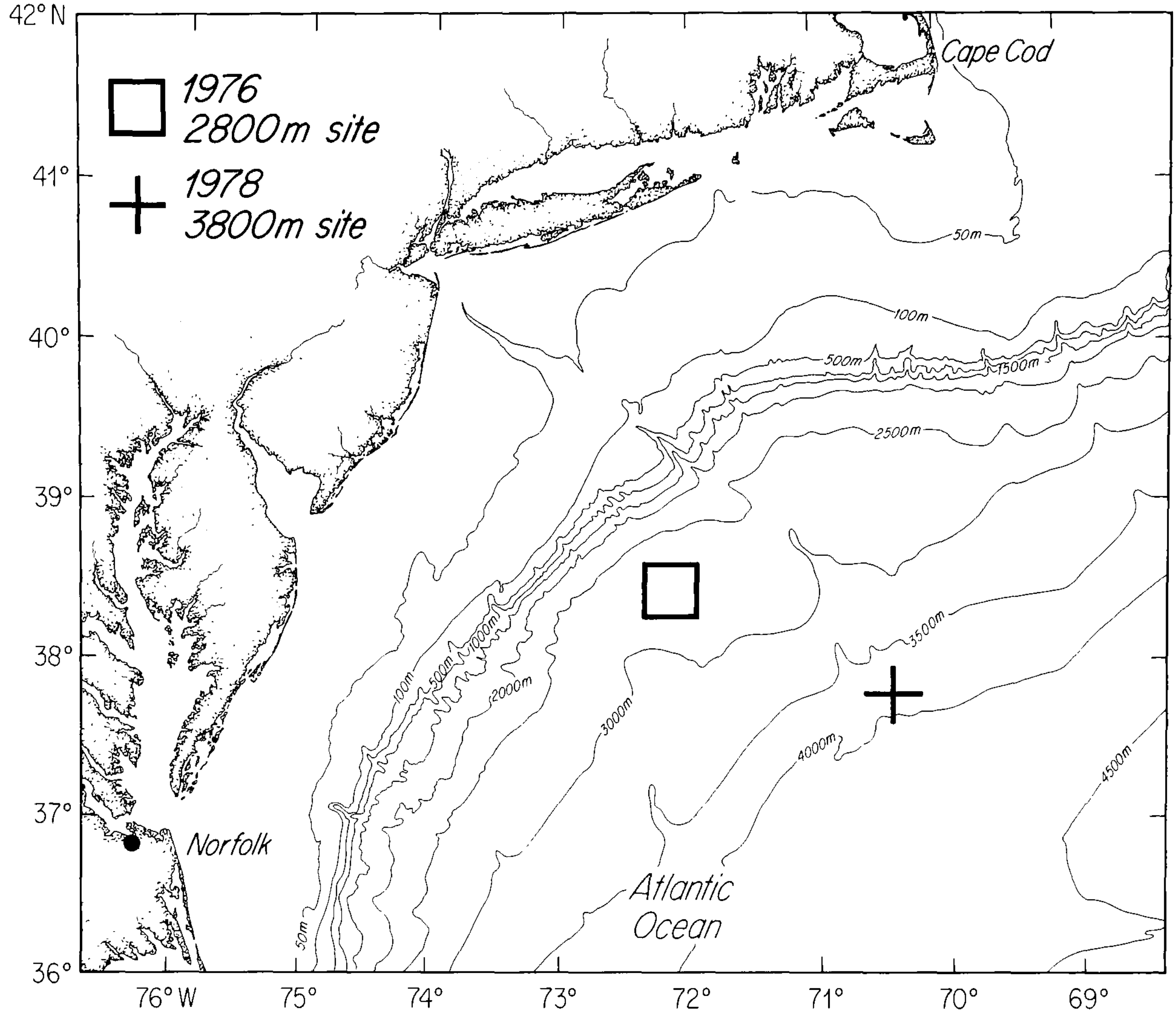

Figure 1: Chart of Atlantic Ocean Disposal Sites

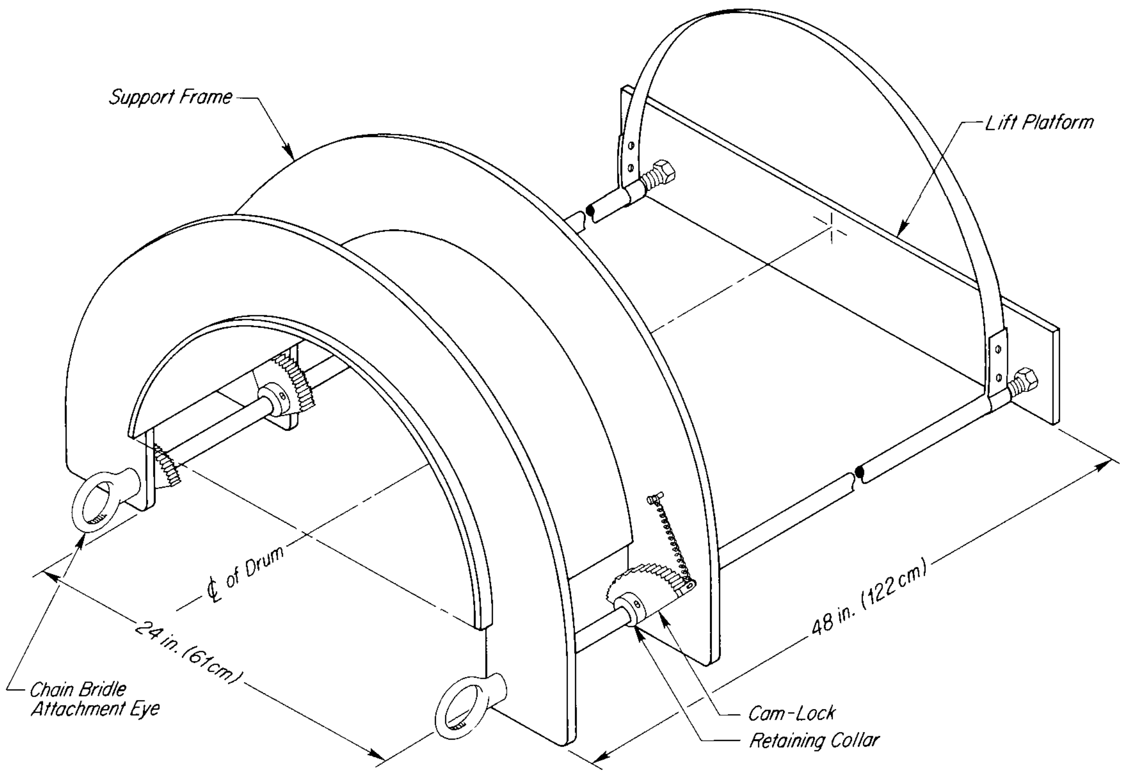

Figure 2: Cam-lock Grabber Waste Package Lift Line Attachment Device

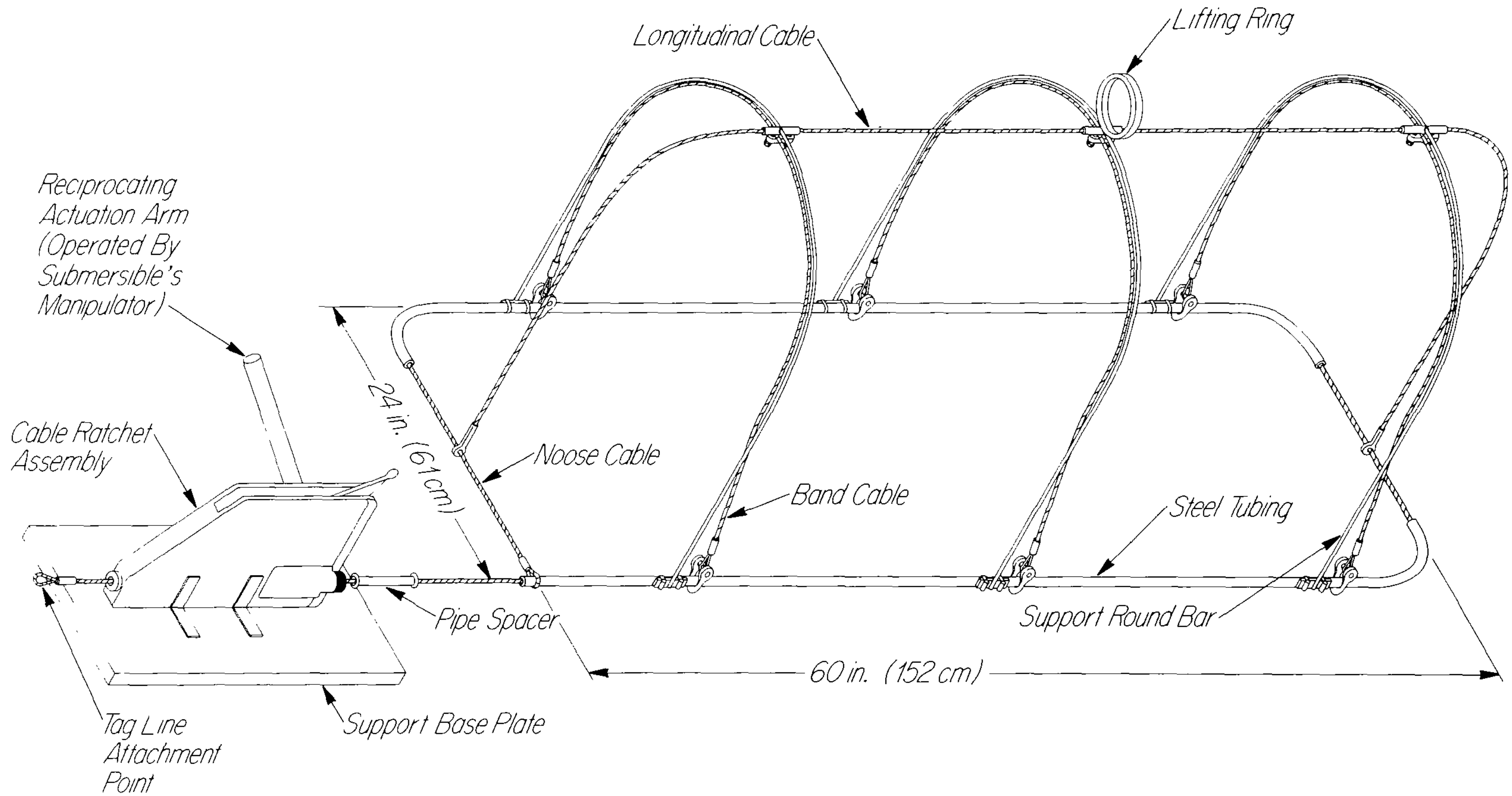

Figure 3: Wire Rope Basket/Harness Waste Package Lift Line Attachment Device

would be attached was located off-center so that when suspended in midwater, the drum would tilt back against the horseshoe-shaped frame and the cams would not be used.

A prototype cam grabber was constructed and successfully tested with a 1400-pound (650 kg.) drum of concrete. The device was heavy and bulky since a strong frame was required to resist the outward forces on the cams during the up-ending operation and the cams had to be located at the end of the drum opposite the lift platform. As constructed, the device was difficult but not impossible for ALVIN to place in position with its manipulator; however, the success of a second attachment device design resulted in this mechanism being designated as a back-up device. It was never actually used for a waste package recovery.

The primary attachment device was a wire rope harness/basket designed to be placed over a waste package and then close around it, using a noose arrangement coupled with a cable gripping rachet assembly. As shown in Figure 3, the basket/harness consisted of three band cables and a longitudinal cable attached to a noose cable housed in tubular steel to maintain its correct shape. The assembly was held in the open position by loose attachment to a lightweight frame constructed of a round steel bar fastened to the steel tubing. A lifting ring was provided to allow the submersible to pick up the assembly as a unit and place it over the LLW package. Once in position, the cable ratchet was used to tighten the noose cable, pulling the band cables around and under the drum. The cable ratchet was operated by placing it, attached to a mounting board, on the sea floor and working the hand lever with the submersible's manipulator. Initially, the ratchet would move toward the basket/harness rather than tightening the noose, but eventually a pipe spacer would contact the basket frame and prevent further relative movement, thereby forcing the noose to tighten with further handle strokes.

The basket/harness assembly was extremely lightweight and, although bulky, could be easily handled by the submersible. Operation of the cable ratchet was time consuming but not difficult, and since the noose cable was also the lift cable, the basket would continue to tighten once lifting began. Only three bands were included in the initial design, but additions could be made in the field if warranted by the condition of the LLW drum selected for recovery.

4.1.3 Lifting Equipment

The direct lift concept required ALVIN to attach the end of the lift line to the LLW package. This was to be done using a 220 foot (100 meter) long, 1 inch diameter (2.54 cm) braided nylon tag line after the end of the lift line was placed within 100 meters of the drum. Use of the ALNAV long baseline acoustic navigation system would ensure that the end of the lift line was properly positioned with respect to the drum.

Upon arrival at the disposal site, a three-transponder acoustic net was to be deployed by LULU, the support ship for ALVIN. The scientific team aboard ALVIN would then locate a suitable LLW package, and carefully determine its position within the navigation network/survey area. After ALVIN surfaced, the CAPE HENLOPEN would lower the lift cable with a clump weight and an acoustic relay transponder attached to the cable's end. Flotation material would be attached above the transponder to keep it off the bottom if the cable went slack. The relay transponder would allow personnel on the LULU to track the lift cable position and instruct the CAPE HENLOPEN how to maneuver so that the cable clump was moved to within 100-meters of the LLW drum (Figure 4). A description of the ALNAV navigation system in provided in the Appendix.

This planned approach to recovery was simple but imposed two requirements on the lift vessel. First, it had to have excellent slow speed maneuverability and, also, station-keeping ability so that the lift cable clump, once in position for attachment to the drum, was not dragged away due to surface ship drifting. Secondly, the need for the relay transponder with flotation meant that the end of the lift line would be a complicated string of equipment requiring special handling gear for launch and retrieval (Figure 5).

The lift vessel available for this recovery, the CAPE HENLOPEN, did have the required maneuverability, but its station-keeping ability while working in deep-ocean waters was unknown. It also lacked a secondary winch that was considered important, during planning, to use in handling complicated equipment. Thus, alternatives had to be devised and substituted. Since reliable station-keeping was not available, all of the Kevlar lift line was run off the winch and had surface buoys attached to it while ALVIN was involved in the attachment phase (Figure 6). Because the secondary winch was not available, the equipment string that would be used was designed for hand-over-hand launching and recovery, utilizing static stoppers. The weight of each segment was kept to a limit that could be moved safely, using the ship's capstans. Figure 5 shows the resulting configuration of the lift line. NOTE: the 1500-pound (680 kg) clump weight was configured for release by ALVIN once the line was attached to the LLW drum being retrieved.

4.2 Recovery Operations

The LULU sailed from Woods Hole for this recovery on July 27, 1976. Participants aboard included Robert Dyer from the EPA Office of Radiation Programs (Project Leader) and Cliff Winget, a WHOI research specialist (ALVIN Group Expedition Leader). On the same date, the CAPE HENLOPEN sailed from Lewes, Delaware. Those aboard included Stephen Dexter of the University of Delaware (Chief Scientist) and Peter Colombo from Brookhaven National Laboratory (Chief of Recovery Operations).

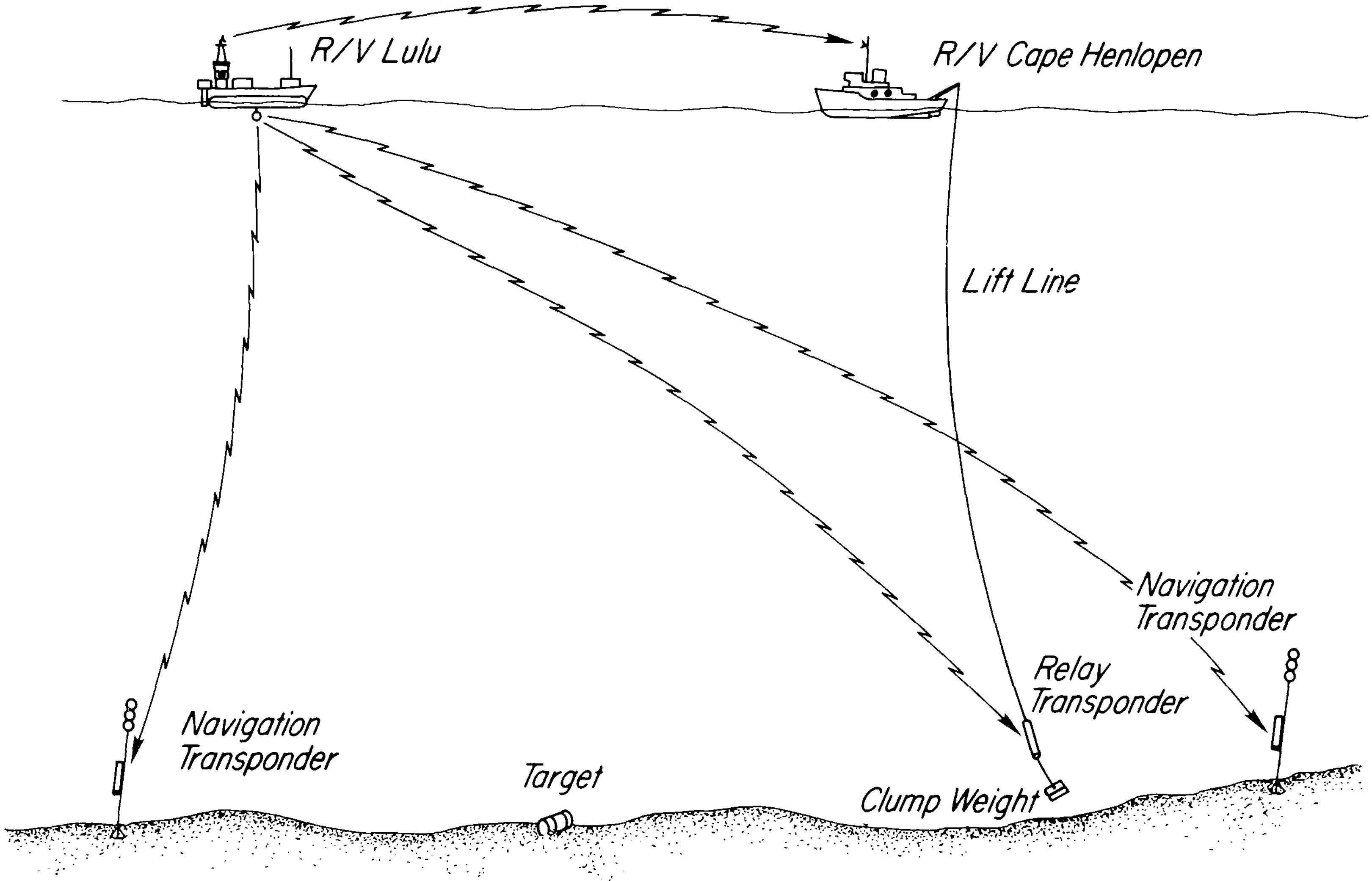

Figure 4: Lift Cable Positioning – 1976 Atlantic Ocean Recovery Operation

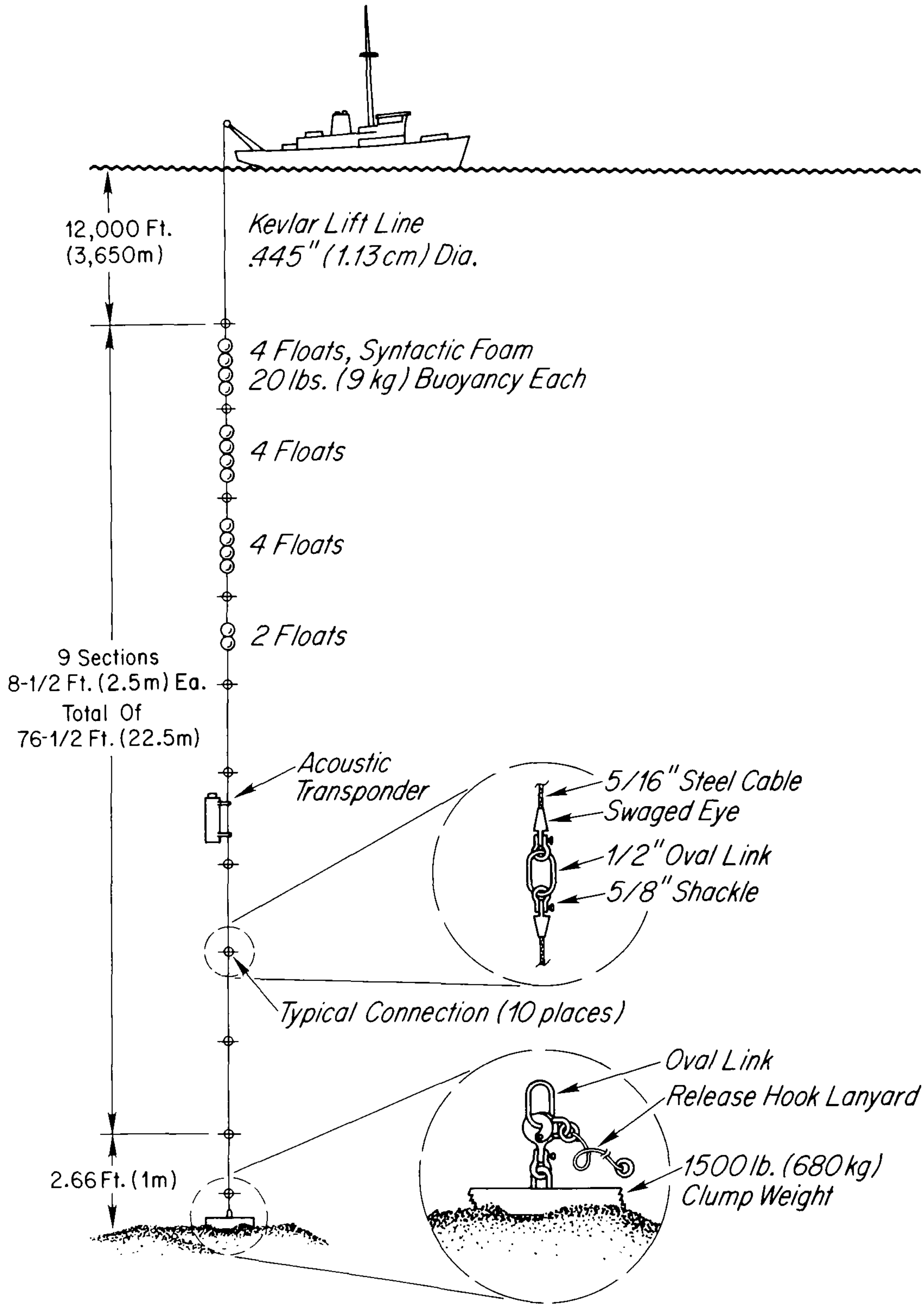

Figure 5: Lift Cable Arrangement – 1976 Atlantic Ocean Recovery Operation

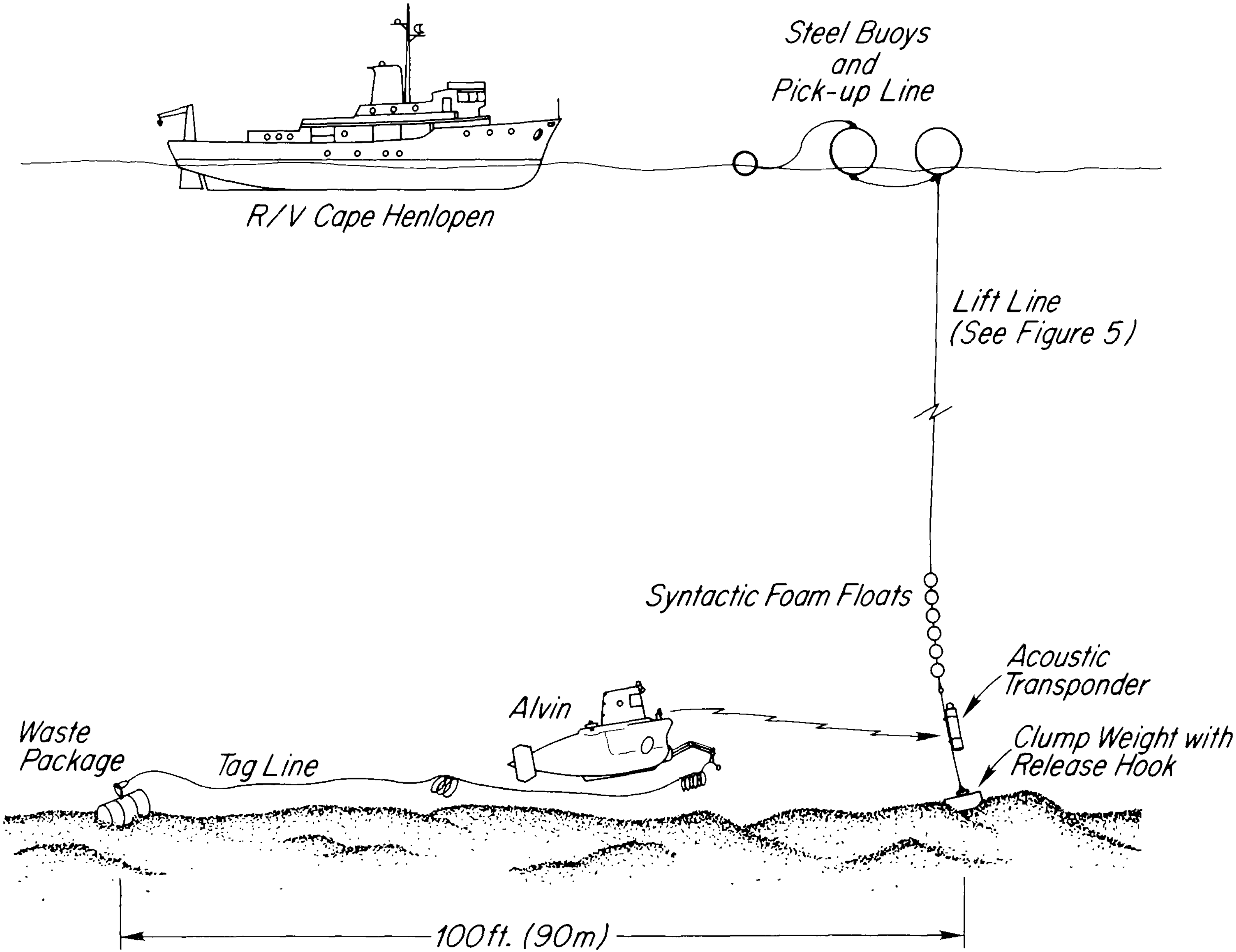

Figure 6: Lift Cable Attachment – 1976 Atlantic Ocean Recovery Operation

The LULU arrived at the site on July 28th and deployed a three-transponder navigation network. ALVIN dive number 676 commenced the following morning, and a suitable 80-gallon LLW package was located for recovery (Figure 7). The waste package was filled with concrete and half buried in the sediment. It showed no deformation due to hydrostatic pressure effects or impact with the bottom on disposal. The cable basket/harness lift line attachment device was deployed without difficulty (Figure 8), and the remainder of that dive was spent collecting biological and sediment samples in the vicinity of the LLW package.

The CAPE HENLOPEN positioned itself, approximately 1 kilometer east of the position of the LLW package, on the evening of July 29th and lowered the Kevlar lift line with clump weight and acoustic relay transponder (Figure 4) until the clump weight was approximately 75 meters above the sea bottom. Maneuvering runs were then made, based upon instructions from the acoustic navigation team aboard the LULU. The limited weight of the clump weight, when in water, coupled with the nearly neutral buoyancy of the Kevlar line made control of the lift line end difficult. Thus, it took approximately twelve hours (until morning on July 30th) to achieve an acceptable placement of the lift line clump weight within 100 meters of the LLW package. Also, by early morning, all of the Kevlar line had been removed from the trawl winch and attached to a pair of 48-inch (1.2 meter) diameter steel buoys. Tag lines with small inflatable floats were attached to the buoys to facilitate recovery operations.

ALVIN then dove again, carrying a 100-meter tag line to connect the LLW package to the lift line (Figure 6). AlVIN next ran the tag line between the waste drum and the lift line, made the required connection, and then detached the clump weight using the safety release hook. No difficulties were encountered.

The CAPE HENLOPEN began final lifting procedures at approximately 2:00 a.m. on July 31st. The steel buoys were recovered first, and then the Kevlar lift line was fed back onto the trawl winch. Approximately six hours later, the LLW package reached the surface (Figure 9). Recovery time was slowed because of the trawl winch level-wind mechanism could not be used with the Kevlar lift line. Thus, manual assistance was needed to obtain a uniform layering of lift line on the trawl winch drum. The last phase of recovery involved retreving the hardware at the end of the lift line and bringing the LLW package aboard the ship. Figure 5 shows the terminating hardware which consisted of 2.5-meter long strings of wire rope connected together with shackles and oval connecting links. the 1500-pound (680 kg) clump weight was attached to the end using a release hook with a lanyard allowing activation by the submersible. The relay transponder was attached to the string approximately 10 meters above the clump weight. Above that, the syntactic foam flotation assemblies were attached as required to counteract the weight of the transponder. Finally, the uppermost string and connecting link were shackled to the Kevlar lift line which, in turn, passed through a large trawl block at the top of the ship's A-frame.

The trawl winch brought the Kevlar line aboard until the first bottom hardware connection point was level with the main deck. A tag line was then hooked into the oval connecting link. Lifting continued until the connection was about to enter the trawl block. In planning recovery operations, the length of the hardware strings had been calculated to allow the lower connections to be on the main deck as the upper connections reached the trawl block. This made it possible to hook a static tag line, secured to the deck, into the lower connecting link and to transfer the load by paying out with the main winch. The lift line was then paid out further while the first tag line was used to manually pull the upper hardware string onboard, where it was secured to the deck. The main lift line was then transferred to the top of the second hardware string and the process repeated.

Recovery of the hardware continued until reaching the tag line ALVIN had attached between the clump weight and the LLW drum. The tag line was 100 meters of 1-inch (2.54 cm) nylon without intermediate attachment points. The ship did not have a winch or capstan suitable for retrieving this line, thus a less direct method was used. The size of the trawl block used at the top of the A-frame had been selected to allow the passage of the tag-line-to-lift-line attachment hardware. Thus, it was possible to bring the tag line aboard through the trawl block until the attachment hardware was about to enter the permanent main deck fair leads for the trawl winch. Soft line stoppers were then attached to the lift tag line at the main deck level and the load transferred. It was then possible to disconnect the Kevlar lift line from the nylon tag line and lead the nylon to a set of bits on deck. Next, the remainder of the tag line was brought aboard hand-over-hand using two capstans in conjunction with a pair of line stoppers. The nylon tag line was continuously secured to the deck bits with minimal slack so that the load would be held in the event one of the stoppers slipped.

Once the steel cable of the LLW drum attachment device reached the level of the main deck, the Kevlar lift line was reattached and used to raise the drum from the water (Figure 9). The LLW drum was held in this position while the level of radioactivity was checked and while tag lines for bringing it aboard were attached. At the same time, preparations were made on deck for storage of the drum in a transport overpack container. The aft deck was covered with a waterproof tarpaulin, with sides elevated to contain drippings from the LLW drum as it was brought aboard, lowered into the transport container and secured with metal bands (Figures 13 and 18). The transport container (a jet engine case) was then sealed shut and purged with argon gas to retard corrosion of the LLW drum during transport to the Brookhaven National Laboratory (BNL) for analysis.

Safety precautions were employed throughout the recovery operation. Access to the stern area of the ship was restricted to a minimum number of required personnel, wearing disposable overclothes which were removed prior to their leaving the stern area. During the recovery, radiation levels were continuously monitored by a BNL health physicist and all persons aboard wore dosimeters during the entire cruise.

Figure 7: Low-Level Waste Package – 1976 Atlantic Ocean Recovery Operation

Figure 8: Deployment of Cable Attachment Basket/Harness by ALVIN

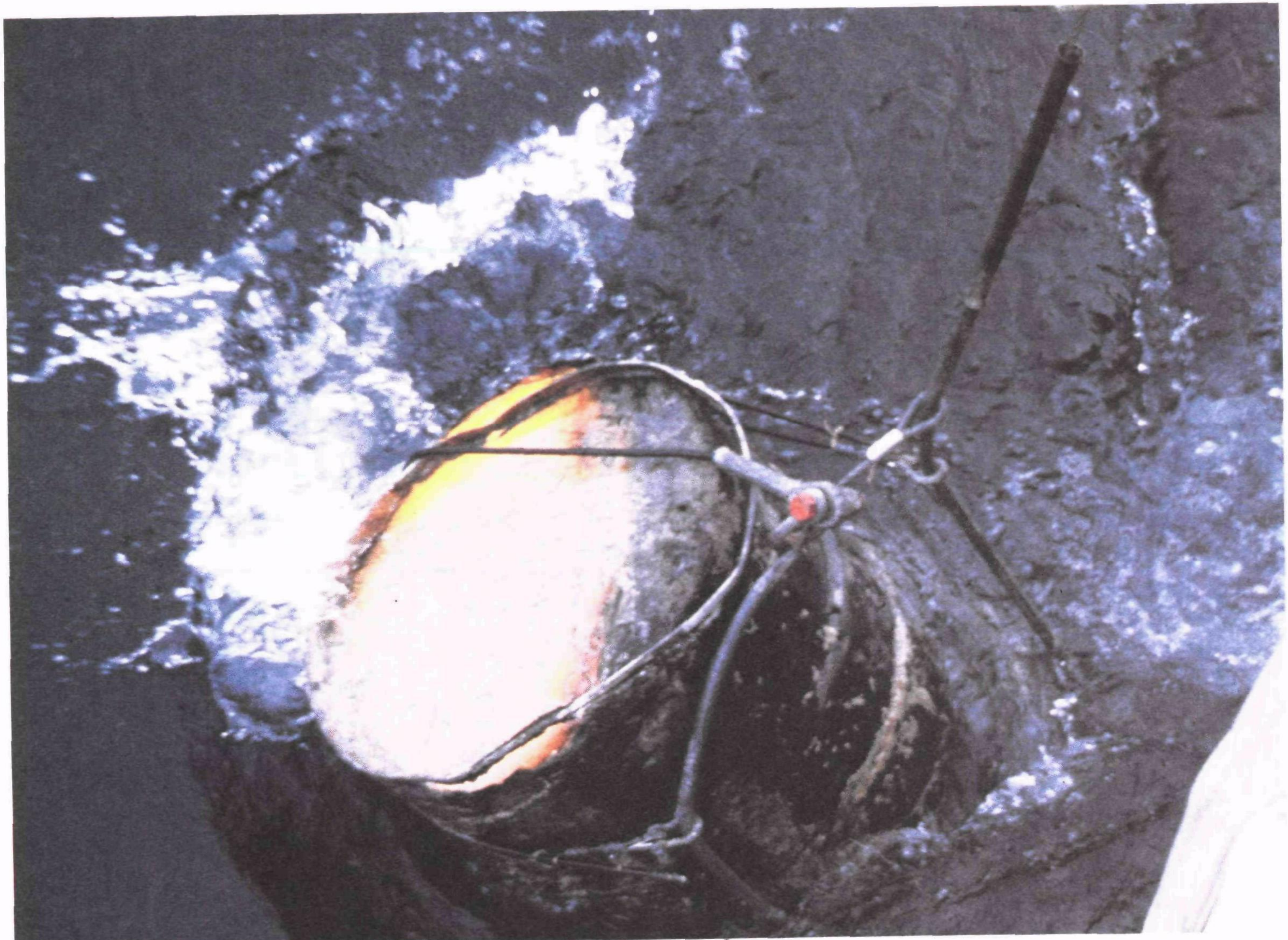

Figure 9: Waste Package at the Surface – 1976 Atlantic Ocean Recovery Operation

5 1977 RECOVERY, PACIFIC OCEAN (FARALLON ISLANDS) LLW DISPOSAL SITE

5.1 Equipment Design and Preparations

The success of the 1976 LLW package recovery from the Atlantic Ocean 2800-meter site led to the planning of a similar recovery in 1977. The Farallon Islands LLW disposal site, located off the coast of California near San Francisco, actually includes two subsites. Subsite A is centered at 37°38'N and 123°10'W with a water depth of 900 meters; subsite B is centered at 37°37'N and 123°18'W with a water depth of 1700 meters (Figure 10). LLW packages were to be recovered from both subsites. A Canadian manned submersible, PISCES VI, and its support ship, R/V PANDORA II were chosen for this recovery operation, along with the University of Southern California's R/V VELERO IV which would serve as the lift and recovery ship.

The WHOI ALVIN Group personnel were retained as advisors since the recovery method was to be similar to that used previously with the ALVIN submersible. The capabilities of PISCES VI and PANDORA II were such that the WHOI personnel were able to use the same type of waste package lift line attachment equipment that was used during the 1976 recovery. The VELERO provided an equipment advantage over the 1976 recovery in that she was equipped with a secondary winch that could be used during the final stages of drum recovery. Surface and submersible navigation would be provided by using the Motorola Mini-Ranger system and a Ferranti ORE, Inc. long baseline acoustic acoustic system.

5.2 Recovery Operations

The VELERO sailed from San Francisco on October 17, 1977. Participants aboard included Robert Dyer from the EPA Office of Radiation Programs (Project Leader), and Michael Smookler of Interstate Electronics Corporation (Cruise Leader).

The PANDORA, with the PISCES submersible aboard, departed on October 18th and arrived on station (900-meter subsite) at approximately noon. Using the Mini-Ranger navigation system aboard VELERO, the PANDORA deployed three acoustic transponders on the bottom. Once the bottom navigation system was in place and operational, the VELERO would then be able to proceed independently to other areas of the Farallon Islands LLW disposal site for sample collection activities, using the Mini-Ranger system. The PANDORA and PISCES would use the acoustic transponder navigation system to locate a suitable LLW package for recovery. Unfortunately, however, the bottom-deployed navigational system did not work properly and the first PISCES dive was unsuccessful due to the lack of a bottom reference point to use in searching for LLW drums.

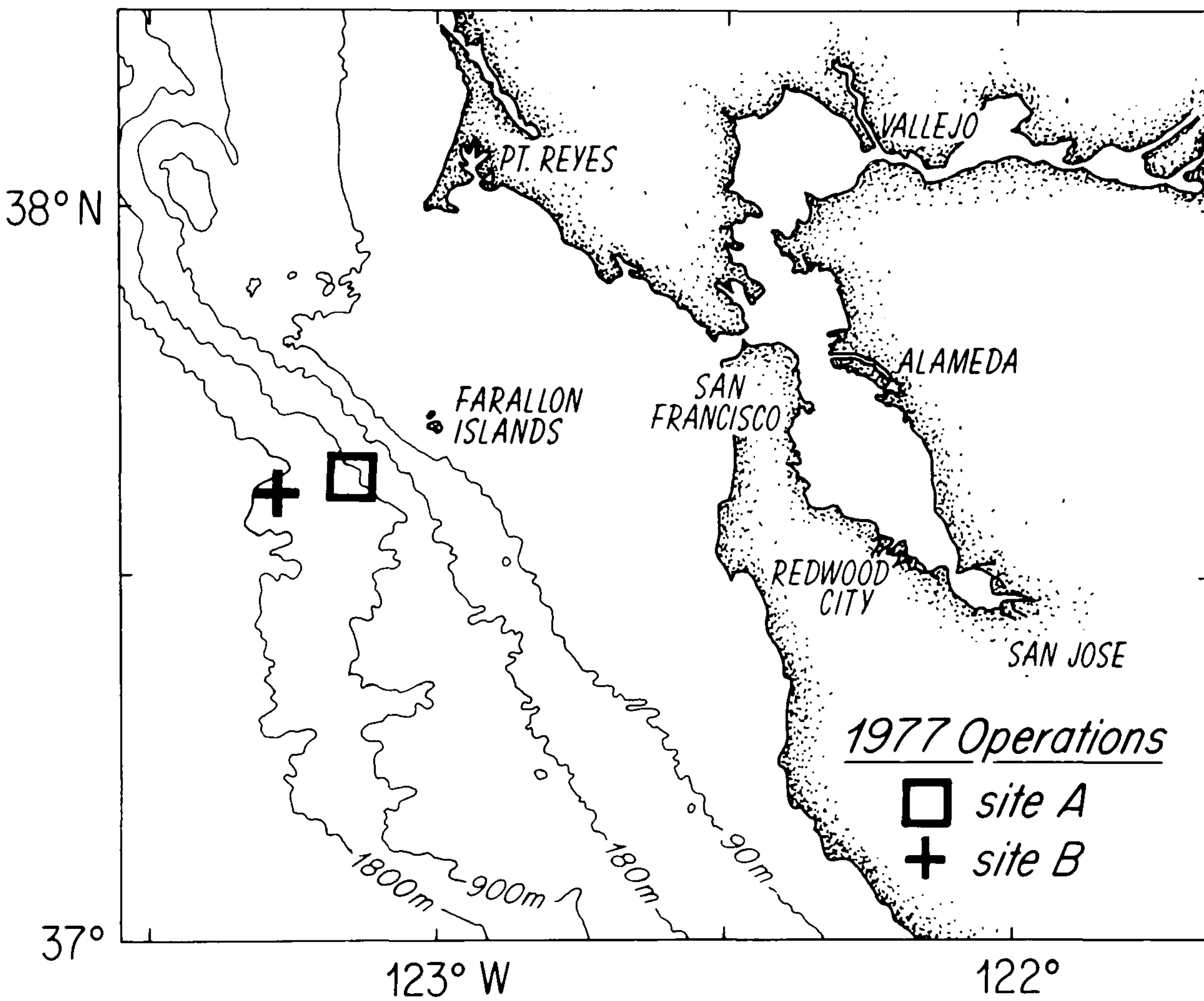

Figure 10: Chart of Pacific Ocean Disposal Site

On October 21st, the PISCES again dove on the 900-meter subsite using an acoustic pinger deployed the previous night as a bottom reference marker. This dive successfully located LLW packages but, without the baseline acoustic navigation system operating, it would not be possible to navigate the lifting line into position near a drum selected for recovery. As an alternative, the direct lift by submersible method was considered. The LLW packages located during this dive were 55-gallon drums with an estimated weight of 875 pounds (397 kg), which was well within the 1500-pound (680 kg) payload capacity of the PISCES.

That evening, after returning to the PANDORA, the PISCES crew adapted the submersible for a direct lift recovery operation (Figures 11 and 12). The WHOI lift line basket/harness attachment device was used in conjunction with a 100-foot (930.5 m) nylon tag line attached to a releasable bridle beneath the PISCES. Once the lifting harness was secured to a LLW drum, the tag line would be attached to the harness allowing the PISCES to surface with the drum suspended beneath it. A second, short line was attached to the tag line at the release point beneath the submersible and then secured to a point which would be above water when PISCES surfaced. This would be an attachment point for the VELERO's main lift line, to be used when transferring the LLW drum from beneath the submersible to the recovery ship.

PISCES was launched again for a recovery attempt on the morning of October 22nd, and returned approximately five hours later with a 55-gallon LLW drum suspended beneath. The VELERO then moved into position and attached its lift line to the drum's tag line. PISCES then released the lift bridle tag line and the drum swung through the water from beneath the submersible to underneath VELERO. Recovery then proceeded, using the secondary winch on VELERO which was able to retrieve the nylon tag line directly without the extra effort and special procedures used in the final stages of recovering the LLW drum from the Atlantic 2800-meter site in 1976.

Safety precautions during this recovery were similar to those employed during the 1976 operations (Figures 13 and 18). Recovery of a second LLW drum, from the 1700 meter subsite, had been planned but poor weather conditions, particularly dense fog, precluded that opportunity. The VELERO then returned to San Francisco where the LLW drum from the 900-meter subsite was prepared for shipment to BNL for analysis.

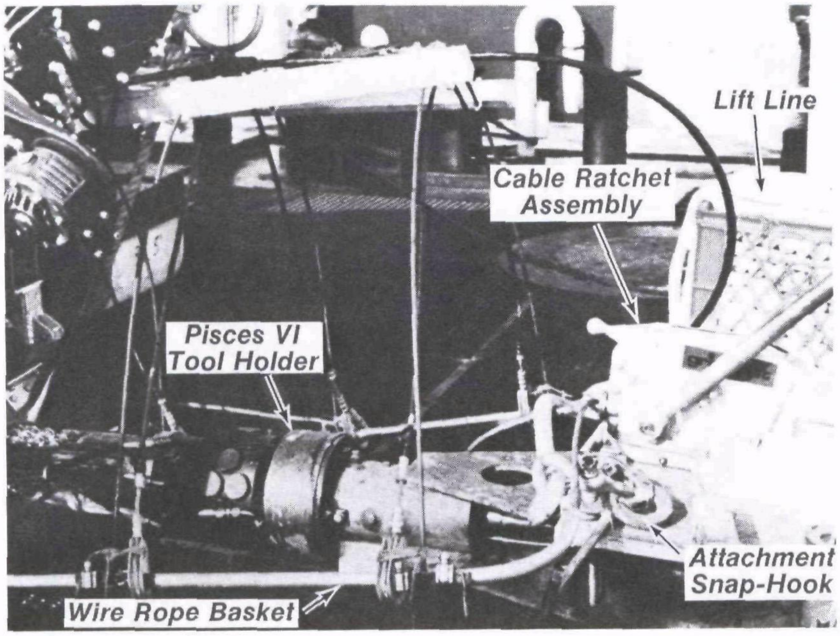

Figure 11: Submersible *PISCES VI* Configured for 1977 Pacific Ocean Recovery

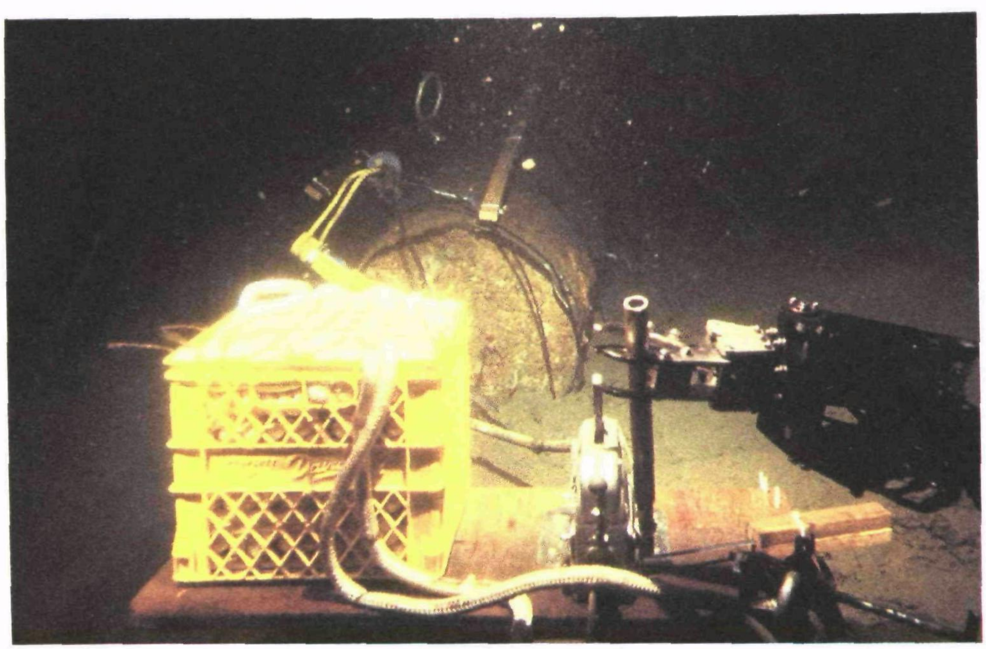

Figure 12: *PISCES VI* Deploying Waste Package Attachment Basket/Harness

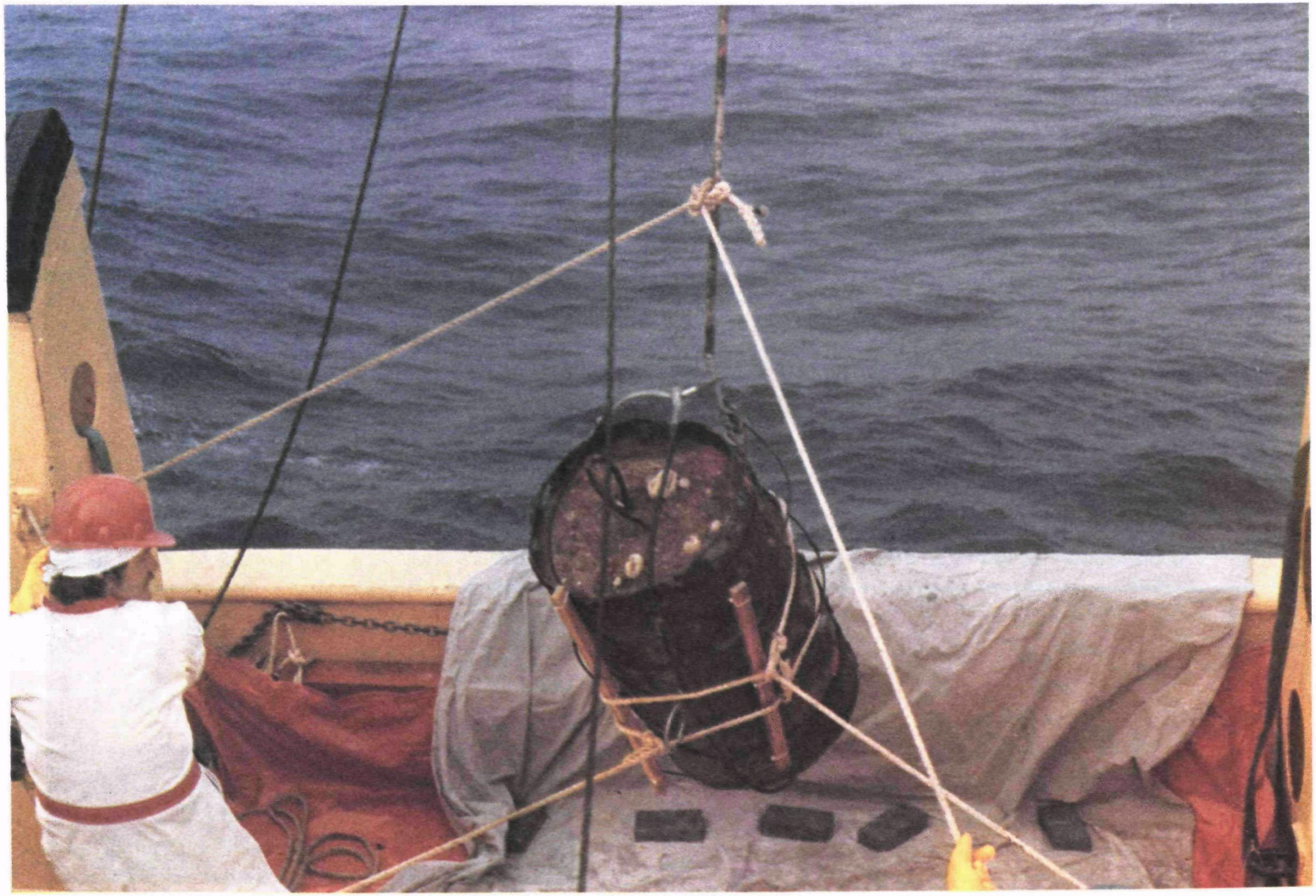

Figure 13: Pacific Disposal Site Waste Package Aboard *R/V VELERO IV*

6 1978 RECOVERY, ATLANTIC OCEAN 3800-METER LLW DISPOSAL SITE

6.1 Equipment Design and Preparations

After successful recoveries of LLW packages in 1976 and 1977, it was decided to attempt recovery of a waste drum in 1978 from the Atlantic Ocean 3800-meter LLW Disposal Site, near the Hudson Canyon (Figure 1). Vessels for this recovery would be: the WHOI submersible ALVIN and its mother ship R/V LULU; and the R/V ADVANCE II, operated by the North Carolina Cape Fear Technical Institute.

Since records indicated that LLW packages disposed at this site were 55-gallon drums and within the ALVIN's lifting capacity, provided that nonessential equipment was removed, it was decided to again use the direct lift recovery method utilized in 1977. Modifications to ALVIN for the recovery included: adding a lift line attachment point underneath the submersible which was secured in place with explosive bolts for emergency release purposes; running a stainless steel cable from the lift point, through a primary release explosive cable cutter, to a pear link that would be the attachment point for the LLW drum tag line; and securing a second line, attached to the link and running up the side of the submersible, to a point that would be above water when at the surface (this was the point to which swimmers would attach the main lift line from the recovery ship). The lift line attachment device was identical to that used previously (Figure 3). A 100-meter, 5/8-inch (1.59 cm) diameter nylon tag line was shackled to the release pear link and provided with a snap hook on the opposite end for attachment to the LLW drum lift harness. This tag line and the lift harness were mounted on ALVIN's forward equipment attachment frame, after the hardware normally carried in that area for scientific sampling was removed (Figures 14 and 15).

The ADVANCE II was well-equipped to serve as the LLW package recovery vessel, with deck gear superior to that available on the two ships that were used for this purpose during the 1976 and 1977 recoveries. The main deck had a large stern A-frame with multiple blocks, a trawl winch and a cargo boom. In addition, two large capstans and a secondary winch were located on the 01 level with fair leads to the A-frame. A 100-meter, 1-inch (2.54 cm) diameter nylon lift line was prepared for use with a capstan when transferring the LLW drum from beneath the ALVIN. Trawl wire and additional nylon lines were also available if needed.

6.2 Recovery Operation

The LULU sailed from Woods Hole on June 20, 1978. ALVIN dive numbers 812 and 813 were conducted at the disposal site on June 23rd and 24th with Robert Dyer from the EPA Office of Radiation Programs aboard as Project Leader. A suitable 55-gallon

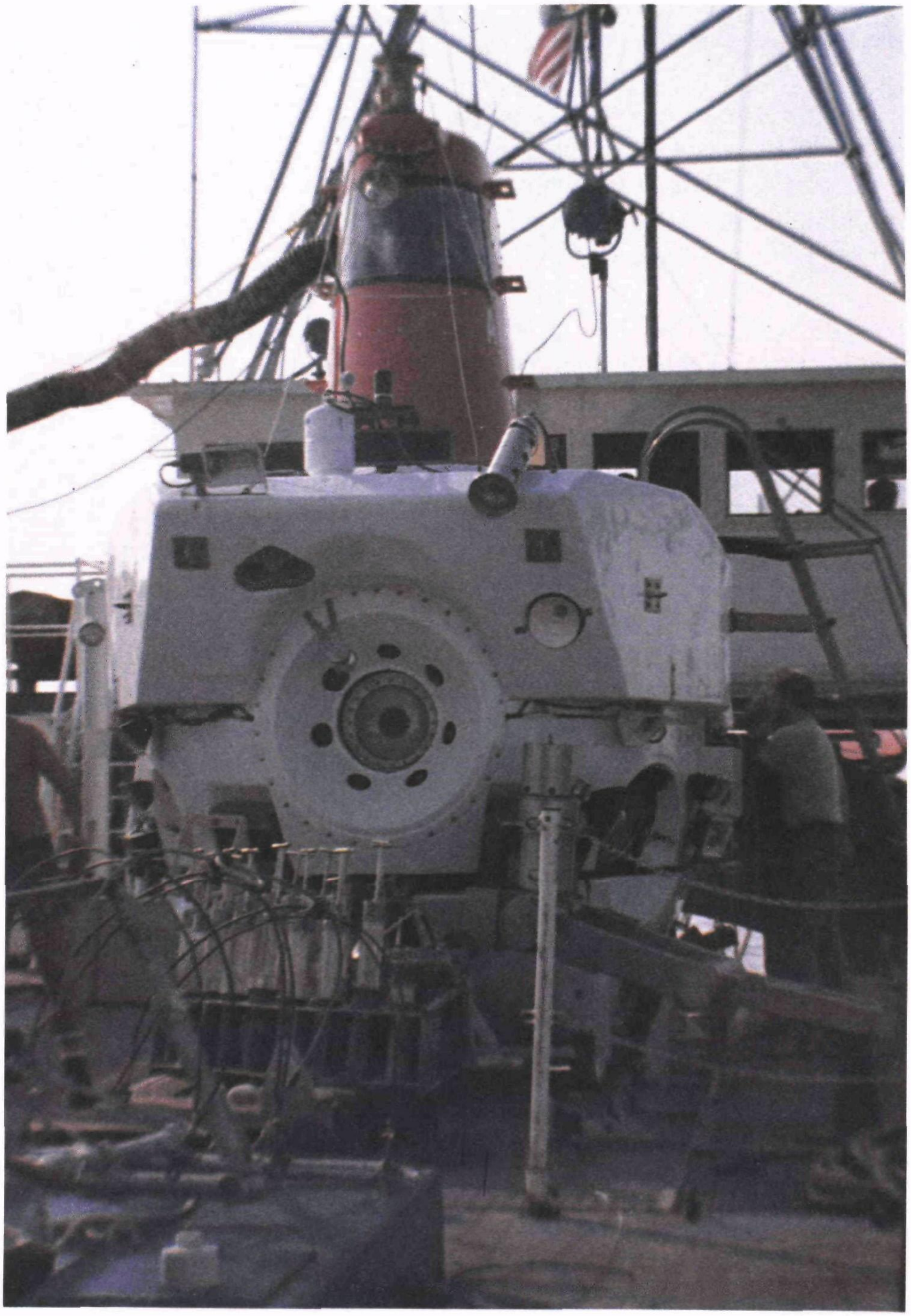

Figure 14: *ALVIN* with Scientific Samplers Mounted on Equipment Attachment Frame

LLW drum was located during the second dive at a depth of 3970 meters. Its position was fixed utilizing the ALNAV navigation system operated from the LULU. That evening, ALVIN was prepared for the direct lift recovery by removing nonessential science support equipment, adding additional syntactic foam flotation material, and installing the releasable lift equipment. Additional lifting payload was also to be obtained by carrying just one observer, rather than the usual two, during the recovery dive. Disposable ballast weights were also attached to an auxiliary release assembly, mounted on the unused starboard manipulator bracket, to compensate for the unusual buoyancy expected during descent due to these modifications.

The ALVIN was launched at approximately 8:00 a.m.on June 25th and returned to the surface six and one-half hours later with the LLW drum suspended beneath it. The dive had included a two-hour descent and a three-hour ascent. The remaining time had been used to relocate the LLW drum, attach the lift harness (Figure 16), and attach the lift line to the harness.

Transfer, at the surface, of the drum from the ALVIN to the ADVANCE II lift equipment was accomplished by using a small boat to transfer the nylon lift line to the submersible, where it was shackled to the above-water attachment point by swimmers (Figure 17). Next, slack was removed from the line and the swimmers made a final check to ensure there were no entanglements. The lift harness, containing the LLW drum, was then released utilizing the explosive cable cutter. The ensuing movement of the recovered drum from under the ALVIN to below the stern of ADVANCE II occurred slowly with no visible shock loads.

The LLW drum and harness were then raised to the sea surface by running the tag line through a center trawl block at the top of the ADVANCE II stern-mounted A-frame, and to a large capstan on the 01 level. The size of the trawl block was selected to allow passage of the shackles and rings used to connect the lift line to the tag line carried by ALVIN. No problems were encountered until the connection between the ALVIN tag line and the LLW drum harness reached the surface. The snap hook used by ALVIN had a T-handle, required for use with the manipulator arm, which would not pass through the trawl block. The ADVANCE II's main trawl wire had to be connected to the cable of the lifting harness to take up the load and remove the snap hook and tag line from ALVIN. Once attached, the trawl wire was used for the remainder of the lifting operation.

On clearing the surface, the LLW drum was checked for radioactivity, tag lines were attached an its overpack transport case was moved into position on deck. The drum was then lowered into the transport case and secured with metal bands (Figure 18). The case was sealed shut and purged with argon as with the other recovered LLW drums. Safety precautions used were the same as those described previously, including the wearing of protective clothing (Figure 18).

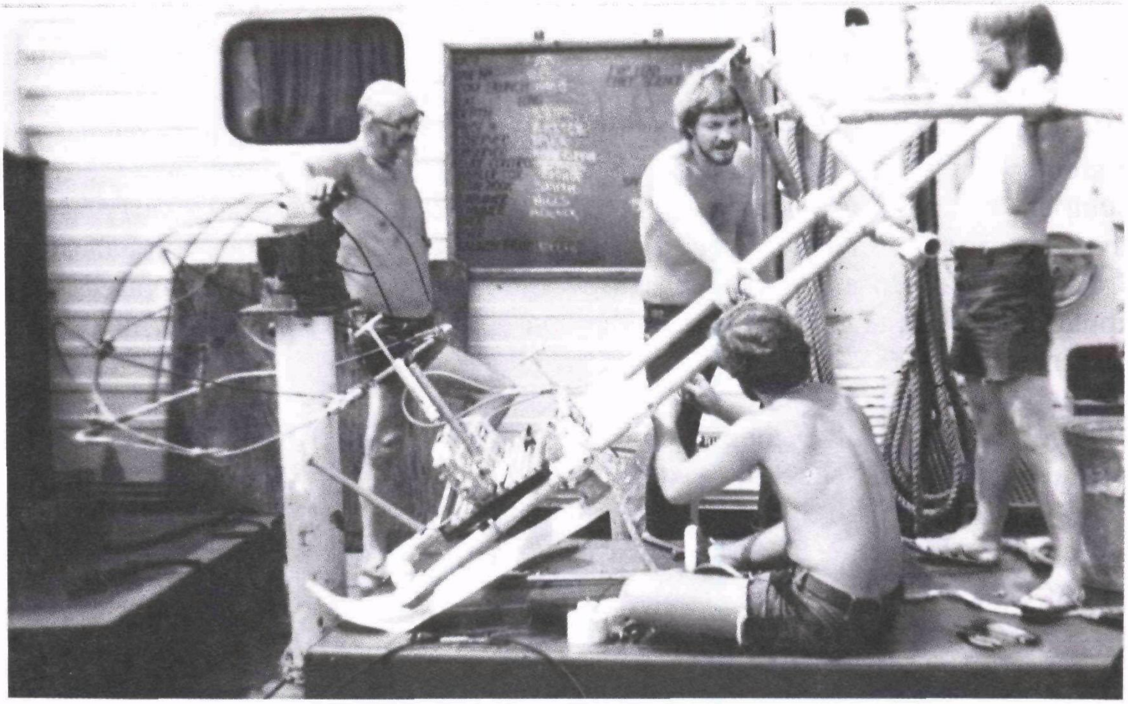

Figure 15: *ALVIN*'s Equipment Attachment Frame Being Outfitted for 1978 Recovery

Figure 16: Lifting Harness in Place Over Waste Package at 3800m Atlantic Site

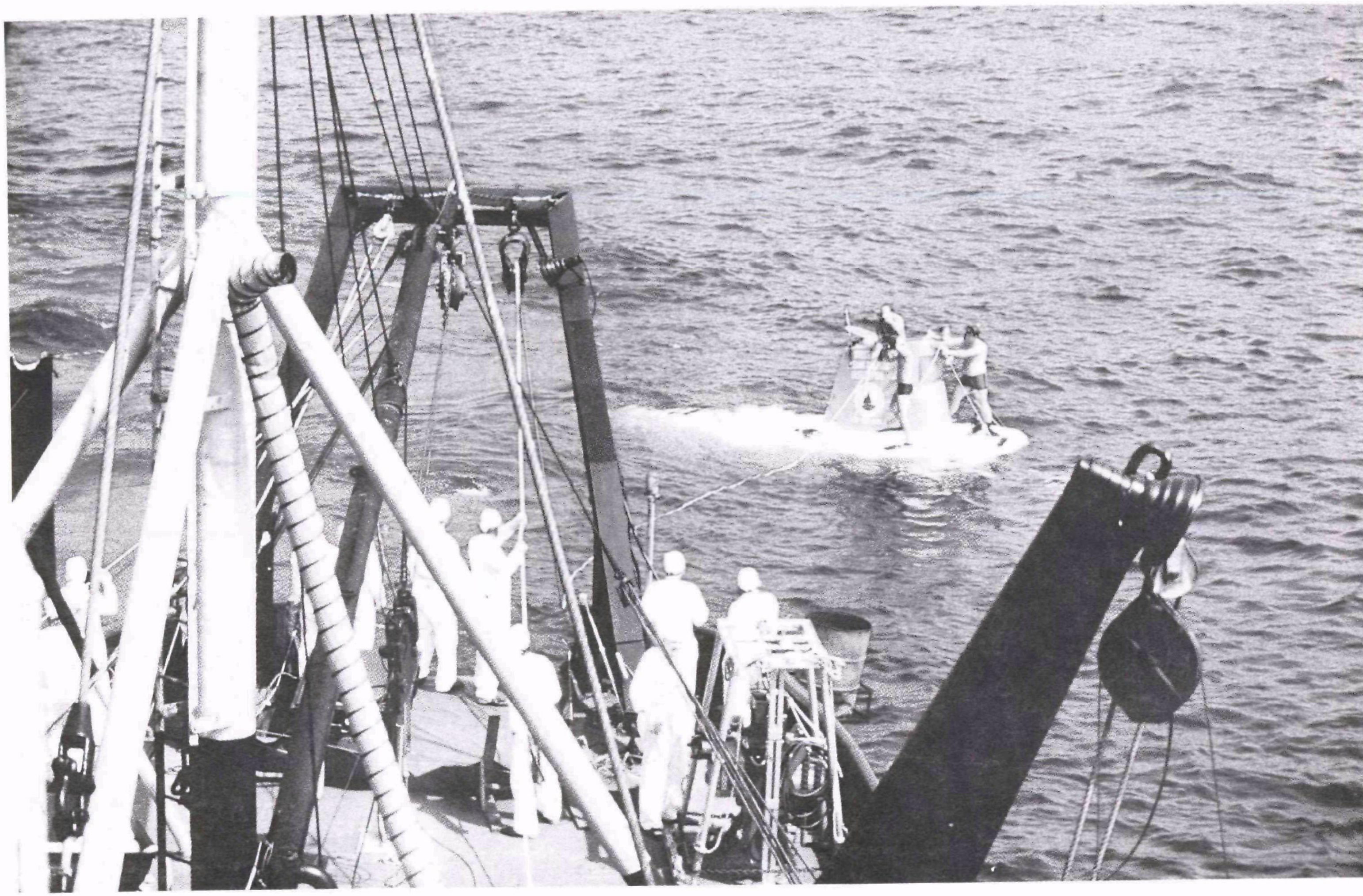

Figure 17: Transfer of Waste Package from *ALVIN* to *R/V ADVANCE II*

7 OBSERVATIONS/COMMENTS

Each of the three recovery operations discussed in this report required two surface ships and a submersible; total daily operational costs were approximately 30,000 1986 dollars.

A single LLW drum was retrieved during each recovery operation. At least one additional day would have been needed at each site to recover another waste package.

The recovery techniques used were similar, allowing each recovery team to learn from the experiences of the previous team. Thus, the third recovery, in 1978, clearly presented the least difficulty despite the fact that the site depth and package weight were close to the ALVIN's maximum limits of 4000 meters and 1000 pounds (450 kg).

The design of the recovery equipment was intended to allow utilization with waste packages of unknown size, weight and general condition. Additionally, the equipment had to be light weight, small, and with little or no power requirements, so it could be deployed by a submersible. All of these objectives were met with the wire rope basket/harness attachment device which performed perfectly on each recovery. The only drawback to its use was the length of time needed for the submersible to tighten the closing noose used the cable ratchet assembly -- and this was really little time when compared to the time of 5-hour time of descent/ascent by the ALVIN for the recovery from 3970 meters.

Weaknesses of the recovery methods are the result of their overall operational complexity. Success was dependent upon too many factors, including: properly coordinated operation of two ships and a submersible; both surface and bottom-mounted navigation systems; and various types of lifting devices/equipment. This level of complexity is not abnormal for work operations in the deep-ocean, but it does decrease chances for success. Also, the required knowledge and expertise, plus attention to detail, needed to achieve success in this complex working environment add to the expense in doing it. For example, the 1976 recovery involved bottom navigation/positioning of lifting cable that required personnel on both ships to work in excess of twelve consecutive hours to achieve success for that part of the recovery. Yet, on the following two recoveries, the surface lift method was not used - thereby decreasing operational complexity and increasing the opportunity for success.

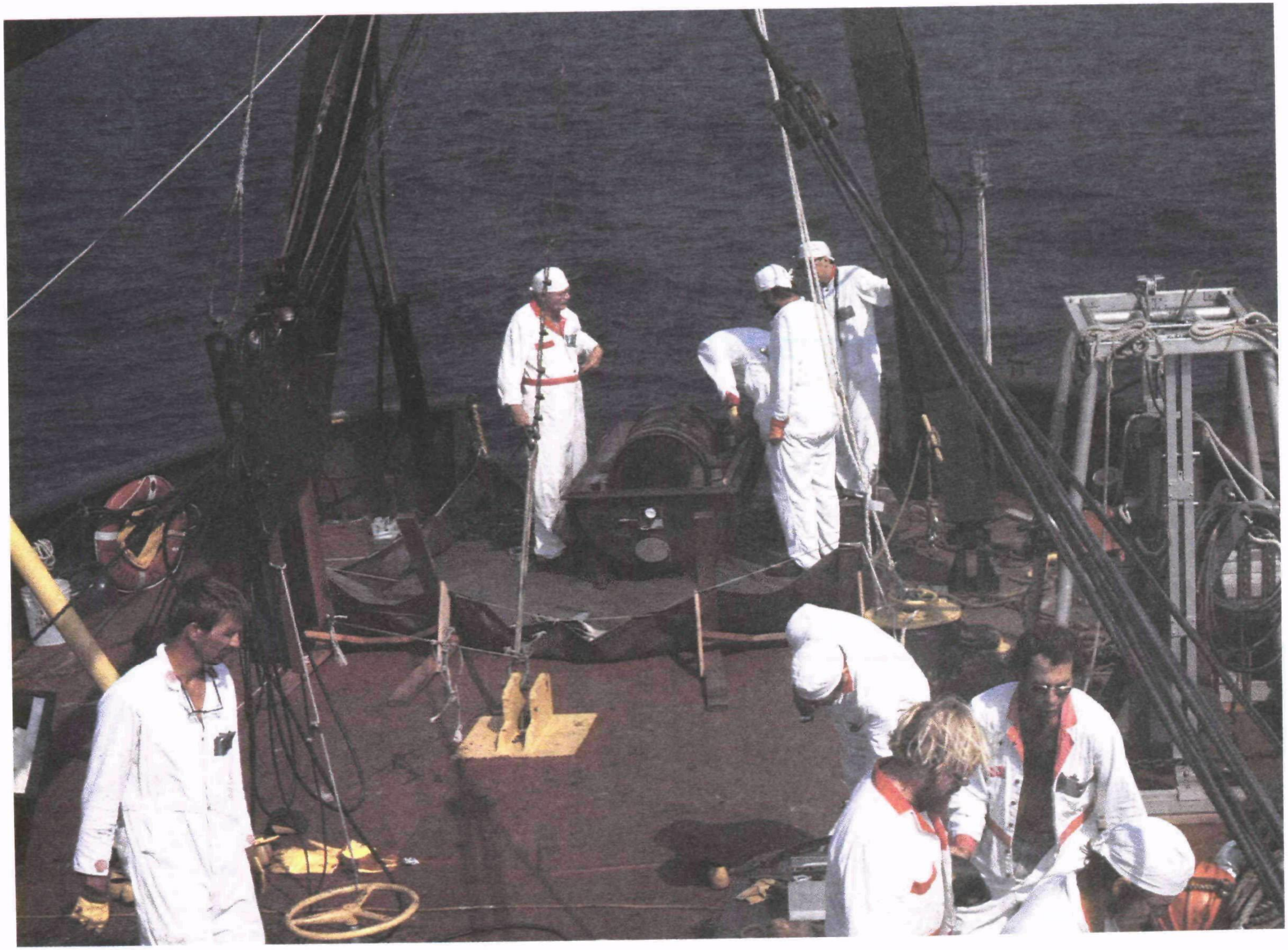

Figure 18: Waste Package in Lower Half of Transport Overpack

8 RECOMMENDATIONS

Waste packages, disposed in the oceans in the future, should be well labelled and standardized in configuration. Considerations for future recovery should be designed in the waste package.

Disposal operations should include verification of correct location and the proper physical condition of packages after reaching the sea floor.

Present technology in the area of cable-controlled undersea robotic vehicles allows the construction of special purpose recovery device/equipment that could be used with most reasonably-sized oceanographic vessels. Such a device could be used to locate suitable waste packages for recovery, to obtain sediment samples and measure radioactivity in the vicinity of LLW drums, and to enclose a drum in a container suitable for direct lifting aboard a surface ship and transport to a laboratory for analysis. Recovery costs for robotic vehicles would be less than required for the operations in this report, since only one (and a surface-type) ship would be needed. Around the clock working operations could result in recovery of three or four waste packages per day. The major requirements for the success of this option are to conduct reasonable planning and design efforts and field testing, prior to waste disposal operations, to ensure recovery of waste packages by this method.

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APPENDIX

ALNAV Long Baseline Acoustic Navigation System

The ALNAV acoustic navigation system was developed at the Woods Hole Oceanographic Institution (WHOI) to provide a method for accurately navigating the submersible ALVIN relative to a fixed location on the sea floor. Before ALNAV was developed, a simple range-bearing (short baseline) system existed on the support ship R/V LULU, which allowed determining the location of the submersible relative to the ship. The accuracy of the range-bearing system was suitable for safety purposes, but it was not accurate enough to allow repeated turns to a given location on the sea floor during a dive or series of dives. One its primary limiting factors was a result of using the surface vessel as a reference point. Use of this reference meant that the submersible's bottom navigation capabilities were limited to the accuracy of the ship's global navigation.

ALNAV (a bottom-referenced, long-baseline system) overcomes this limitation and also provides an inherent accuracy due to the acoustic principles involved. The system utilizes a network of bottom-moored acoustic transponders. The transponders are placed in the area of interest by the surface ship and are designed to listen for a specific acoustic frequency f_o. When this frequency is received, each transponder transmits at a different frequency (f_1 to f_n). In the simplest mode, the network is used by sending an f_o acoustic pulse and determining the times required to receive the f_1 through f_n replies. These times are roughly proportional to the distance between the sender/receiver and each transponder. This information, however, is not sufficient to allow plotting a position for the sender/receiver. Before this can be done, it is necessary to determine the positions of the transponders relative to each other by conducting a survey.

The survey computer programs presently used by the ALNAV system are configured for a two or three transponder net. They require as inputs, accurate pulse travel times for all transponders from at least six survey stations. This information is then used to calculate the location of the individual transponders relative to each other in three dimensional space. Once this information is available, other ALNAV programs can plot the position of a sender/receiver relative to the net with an accuracy dependent on the accuracy of the survey.

Following completion of the survey the ALNAV system can be used in three different navigation modes: ship-ship, ship-fish, and ship-submersible. The ship-ship mode is the simplest in that the ship sends the interrogate acoustic pulse and receives the replies. ALNAV calculations result in a position for the ship relative to the net. The ship's independent surface navigation systems (Loran C, satellite navigation, etc.) can then be used to determine the net's location in global coordinates.

The ship-fish mode differs in that the ship transmits an interrogate pulse at f_x, not the receive frequency of any of the net transponders, but rather the receive frequency of a relay transponder. This special transponder is designed for attachment to a towed fish or any other vehicle in the water column for which navigation is desired. It receives frequency f_x and replies at frequency f_o, the frequency of the net transponders. These, therefore, receive the relay transponder's reply and transmit their own replies. The ship determines the reply times for the relay and net transponders, thereby obtaining enough information to determine the **X, Y, Z** position of the relay transponder relative to the net.

The ship-submersible mode is almost identical to the ship-fish mode except that the submersible transmits frequency f_o on a timed basis rather than depending on receipt of a ship generated f_x pulse. This has the advantage of eliminating one acoustic path and renders the system less sensitive to problems resulting from the submersible's acoustic noise level, since the submersible does not have to detect an incoming f_x signal. For this mode to function, both the submersible and the ship must have accurate, synchronized clocks to allow the ship to determine when the submersible issues its f_o pulse in order to time the replies.

The above description is a simplification of the complexity of the ALNAV system. Both the hardware and software have been under constant revision since the prototype version was first used in 1968. The modes discussed above do not include submersible-submersible, since until 1985, the computers required for the position calculations would not fit within ALVIN's pressure hull. The references at the end of this appendix provide more detailed information.

ALNAV, or a similar navigational capability, is essential for object recovery operations of the type discussed in the body of this paper. Initially, accurate navigation is required to conduct a search, although in recent years, Doppler sonar systems have become available which allow an accurate search pattern to be run without a bottom reference. Once a target is located, it is usually necessary to mark its location in a manner which will allow the search vehicle or specifically-configured recovery vehicle to return to it at a later time. All of the low-level radioactive waste package recoveries discussed in this report involved separate search and recovery operations, with the bottom navigation capability providing the means for repeatedly locating the selected target LLW package. The 1976 recovery also involved using ALNAV in the ship-fish mode for positioning the lift line clump weight close enough to the waste package target for tag line attachment. This required a position accuracy of better than 100 meters, well within the ALNAV accuracy of one percent of water depth.

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16. ABSTRACT

This report presents the techniques used to recover low-level radioactive waste packages from three deep-ocean disposal sites: Atlantic 2800-meter, Atlantic 3800-meter and the Pacific (Farallon Islands) 900-meter. The design of the recovery equipment and its utilization by the submersibles ALVIN and PISCES VI is described. Considerations for future waste disposal and recovery techniques are provided.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
1. low-level radioactive waste 2. recovery operations 3. deep-ocean disposal sites 4. submersibles 5. ALVIN 6. PISCES VI		

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