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Recovery of Low-Level
Radioactive Waste Packages
from Deep Ocean Disposal Sites

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A handwritten signature in black ink, appearing to read "R. C. Spindel", is positioned above the name of the Chairman.

Robert C. Spindel, Chairman
Department of Ocean Engineering

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1 Introduction

The 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, waste was routinely embedded in concrete contained in steel drums and dumped primarily at three designated Atlantic and Pacific disposal sites with depths ranging between 900 and 3800 meters. Approximately 75,000 low-level radioactive waste packages were disposed of in this manner before ocean dumping was terminated in 1970 following the recommendations of the Federal Council on Environmental Quality in a report to the President¹.

Increased environmental concern for ocean waste disposal is evident in research, legislation, international treaties, and the activities of the U.S. Environmental Protection Agency (EPA), administrator of U.S. policy regarding ocean waste disposal. As a first step in developing effective controls, the EPA initiated a program designed to determine the effectiveness of past disposal techniques. Surveys of Atlantic and Pacific sites were conducted by the EPA in 1974 and 1975 using both manned and unmanned submersibles with the goal of assessing the physical condition of the containers and the near-field distribution of any released wastes².

Early controls on the packaging of the low-level radioactive waste were aimed at ensuring that the packages reached the 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 with the majority being between 55 and 80 gallons, having weight in water of 550 to 1400 pounds (250 to 650 Kg); AEC regulations required a minimum of 550 pounds. Internal configurations frequently included an inner container housing the waste material surrounded by concrete, which filled the remainder of the drum. These containers were, in fact, pressure vessels with concrete walls and end caps, and many configured in this manner reached the bottom distorted as a result of implosion due to hydrostatic pressure.

The early EPA surveys 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 was awarded a contract to develop a method for recovering selected waste packages from the Atlantic disposal site to allow more detailed study. Operations conducted in July of that year resulted in the first attempted and successful recovery of an 80 gallon LLW package from a depth of 2800 meters. Subsequently, the method was used in 1977 to retrieve a LLW package from a depth of 900 meters at a Pacific site near the Farallon Islands, and again in 1978 in the Atlantic from a depth of 3800 meters. These were the first three radioactive waste packages retrieved from formerly used low-level waste disposal sites in the ocean.

2 Discussion of the Problem

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: 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 radioactive waste 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

Ocean disposal sites were originally designated by the Atomic Energy Commission with the actual disposal operations being conducted by licensed contractors. In accordance with requirements at the time of disposal, each container was labeled to provide a reference number and an indication of the contents. Records were kept for each site giving the location, date, quantity and reference numbers for all disposed materials. Disposal site surveys using a towed camera system conducted by the Atomic Energy Commission in 1957, 1960, and 1961 found no evidence of packaged radioactive wastes in the Atlantic and Pacific disposal sites investigated³. Clearly, a navigation problem existed, either on the part of the dumping contractors or the survey ships.

The EPA surveys of 1974 and 1975⁴ were more successful in locating LLW packages, and recovery operations were designed to accommodate the positions and depths determined at that time. The number of target containers observed ensured that a submersible would find packaged waste at sites located with reasonable surface navigational control. This, however, was only part of the problem. Many of the containers were found to be inadequately labeled, or damaged and perhaps leaking, making recovery more difficult. Without the label, the hazard of the contents was unknown, and a damaged drum could deteriorate further by the stress imposed during the lifting operation. The only reasonable approach would be to locate a visibly intact drum of known content and focus on its recovery. This would necessitate a precision bottom navigation system, both for use in the search process, and for relocating the selected drum on the subsequent submersible dives required for the attachment of the recovery equipment.

2.2 Lift and Recovery Equipment Attachment

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

The disposal containers were often constructed from 55 gallon oil drums. In many cases, the length of the container was increased by welding half of one drum to the top of another.

The weight of the containers would vary depending upon the 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 containers had attached lifting bails (handles), but because of expected deterioration due to the length of time submerged, these were considered unreliable. 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 or the ridges around the middle. A device was required which could provide a reliable link between a lift line and a heavy cylinder partially submerged in sediment, in any orientation, without relying on any characteristic of the cylinder other than its general shape. This device had to be strong enough to handle 2000 pounds in air, yet light enough to be handled by the manipulating arm of a submersible.

2.3 Lift Method

Two methods were available for returning a heavy object to the surface from the sea floor: 1) attachment of a flotation package, and 2) direct lift using a surface winch. In the case of a low-level waste package, control of the lift speed was considered to be important, since too rapid an ascent might cause the drum to rupture due to entrapped water not being allowed adequate time for pressure equalization. If a flotation package was designed for a slow ascent, ocean currents could cause it to experience considerable horizontal displacement. Locating such a package once it reached the surface could be an added difficulty. Direct lift with a surface winch would solve both of these potential problems, but at a cost of increased operational complexity.

2.4 Surface Handling

As a general rule, successful handling of heavy objects at sea requires passing through the air-sea interface as quickly as possible. Potentially hazardous waste packages, however, cannot be simply pulled from the water and placed on deck without carefully considered safety measures. These measures must include a means for adequately evaluating the radiation hazard before the container is brought aboard, and a method for containing all material that might break off or seep from the drum once aboard. This former requirement would likely result in holding the drum over the side, clear of the water for an extended period, thus prolonging the time during which maximum stresses are placed on the lifting gear due to ship motions.

3 Preliminary Equipment Investigations

Early in 1976, the Deep Submergence Engineering and Operations Group (*ALVIN* Group) of the Woods Hole Oceanographic Institution (WHOI) entered into a contract with the U.S. Environmental Protection Agency for the design and demonstration of a system capable of retrieving low-level radioactive waste packages. Various retrieval methods were considered during preparation of the initial proposal, but all centered upon using the manned submersible *ALVIN* to locate a suitable container and attach a lifting device. Four methods for performing the actual lift and recovery were investigated and are outlined in the following subsections.

3.1 Constant-Buoyancy Lift Package

This method utilized a constant-volume flotation package to be attached to the waste container by the submersible. The package would have in excess of 1400 pounds (650 kg) of buoyancy for use with an 80 gallon container, and therefore, a releasable ballast weight would be required to allow the flotation package to free fall or be carried to the 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 were essentially constant with depth.

Using syntactic foam with a density of 36 pounds/cubic foot (576 kg/cubic meter) required a package 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 the package together. A descent weight of approximately 2000 pounds (910 kg) would be required.

The largest readily available deep ocean glass sphere was 17 inches (43.2 cm) in diameter providing 52 pounds (23.6 kg) of buoyancy. Approximately 30 of these buoyancy spheres would be required to lift an 80 gallon waste package, and again, approximately 2000 pounds (910 kg) of releasable ballast weight would be required.

Flotation packages constructed from either of the above materials could be launched from a reasonably equipped support ship and allowed to free fall to the bottom, hopefully landing near the waste package to be recovered. Attachment to the drum and release of the ballast weight would then be done by the submersible, which would also move the package closer to the drum if required.

Multiple problems existed for this general method. The flotation packages were large, making surface and submerged handling difficult. The buoyancy was fixed in advance and therefore the speed with which a waste package returned to the surface could not be closely controlled without knowledge of the package's weight in advance. Special hardware additions such as strobe lights and radio beacons would be required to ensure the ability to locate the flotation package and waste container once they reached the surface. Finally, and perhaps most importantly, when the submersible released the flotation package ballast weight, the waste package would travel upward through the water column above the submersible such

that failure of the attachment device could result in the waste package falling back upon the submersible. All of these problems could be solved however, and this general method was considered a realistic possibility.

3.2 Variable-Volume Lift Devices

This category included lift bags incorporating gas generators to provide flotation only when required. They had the advantage of decreased size and mass compared to fixed flotation packages, and therefore ship and submersible handling was 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 waste package recoveries.

With the exception of handling considerations, the other problems associated with fixed flotation packages including ascent speed control, surface location difficulties, and danger to the submersible during ascent, also existed for variable volume lift designs. Again, they could be solved, but due to the development effort required to obtain a safe package of suitable buoyancy, this method was not proposed.

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 make an attachment between the lifting device on the waste package and the lift cable. A major problem, however, was that the submersible would not be able to move the end of the cable because of its weight, and therefore the cable end would have to be placed close to the desired container by the surface ship. This type of operation had been conducted by the Woods Hole Oceanographic Institution in the past, and the following method was proposed: accurate submersible bottom tracking would be accomplished utilizing the ALNAV long baseline acoustic navigation system (see Appendix I). Once a suitable container was located during an *ALVIN* dive, its position would be known within the navigation net formed by the bottom-moored acoustic transponders. After *ALVIN* surfaced, the lift cable would be lowered to within a few hundred meters of the bottom with a releasable weight and a marker acoustic transponder attached to the end. The surface ship would then maneuver the end of the cable into the correct position by tracking the marker transponder within the navigation net. Once this was accomplished, sufficient cable would be paid out to allow the weighted end to rest on the bottom. Finally, *ALVIN* would dive again and attach a lifting device to the selected waste package, connect this device to the lift cable using a suitable tag line and release the lift cable weight.

None of the problems associated with the flotation package concepts were present with this method, but there was a submersible safety hazard. During the attachment phase of the

operation, *ALVIN* would work directly beneath a long cable leading to the surface. Should the cable part, it could conceivably fall across the submersible, pinning it to the bottom. The proposed solution was to use a lift cable with minimal water weight, such as polypropylene or Kevlar.

3.4 Submersible Direct Lift

A concept not included in the original proposal was direct submersible lift wherein the waste package would be brought to the surface via a tag line attached to the submersible. If done with proper safety precautions, this method was simpler than those proposed, but it required the submersible to have at least a 1400 pound (650 kg) payload capacity — more than that available with *ALVIN* at the time.

4 1976 Atlantic Ocean Recovery

4.1 Equipment Design and Preparations

4.1.1 General Considerations

The U.S. Environmental Protection Agency (EPA) accepted the Woods Hole Oceanographic Institution's proposal for a waste package retrieval to be conducted in July 1976. The selected site was a one-hundred square mile (256 km^2) disposal area centered at $38^{\circ}30'N$, $72^{\circ}06'W$ and having an average water depth of 2800 meters (Figure 1). The WHOI *ALVIN* group personnel again reviewed the proposed recovery methods and selected the surface ship direct lift concept. The submersible safety problem associated with lift cable weight was solved by specifying the use of a .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 .02 pounds per foot (30 g/m). Because of its low stretch characteristics, this cable allowed use of a standard trawl winch rather than a traction machine, which might be required for use with other lightweight synthetic lines.

ALVIN's support ship, *R/V LULU*, did not have a long-line lift capability and therefore *R/V CAPE HENLOPEN* of the College of Marine Studies, University of Delaware, was chosen as a second operational support vessel. *R/V CAPE HENLOPEN* had a standard trawl winch suitable for the Kevlar line, but it lacked a secondary winch for use in the hand-over-hand operations required for the final stages of the lift. Also, the level-wind mechanism on the trawl winch was configured for 1/2 inch (1.27 cm) diameter wire and could not be adjusted properly for the Kevlar. With those exceptions, *R/V CAPE HENLOPEN* was well suited for the task, being of medium size, easily maneuverable, and having a reasonably large clear aft deck area.

4.1.2 Lift Line Attachment Devices

Design of a lift line attachment device was of critical importance and began with a review of the concepts considered in the preparation of the Woods Hole proposal. It was concluded that although the concepts were feasible, they had the common fault of dependency on the waste container's strength to ensure a secure 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" requiring a reasonably intact and solid drum (Figure 2), and a wire rope harness assembly which required only that the drum not fall apart under its own weight (Figure 3).

The mechanical cam-lock grabber was intended for use on a partially buried drum lying horizontally. The cam locks were designed to grip the container 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 up on end,

Figure 1: Chart of Atlantic Ocean Disposal Site

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

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

placing its weight on a lift platform. The chain bridle to which the lift line would be attached was located off-center so that when suspended in mid-water, the drum would be tilted back against the horseshoe-shaped frame and the cams would no longer be in use.

A prototype cam grabber was constructed and successfully tested with a 1400 pound drum (650 kg) 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 and it was never actually used for a waste package recovery.

The primary attachment device was a wire rope harness or basket designed to be placed over a waste container and then closed around it using a noose arrangement coupled with a cable gripping ratchet 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 the correct shape. The assembly was held in the open condition by loose attachment to a lightweight frame constructed of steel round 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 waste package of interest. 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 rather than tightening the noose, but eventually a pipe spacer would contact the basket frame preventing further relative movement and 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 the lift began. Only three band cables were included in the initial design, but additions could be made in the field if warranted by the condition of the 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 waste package selected for recovery. This was to be done using a 220 foot (100 meter) long, 1 inch diameter (2.54 cm) braided nylon tag line, and therefore the end of the lift line had to be placed within 100 meters of the selected drum. Use of the ALNAV long baseline acoustic navigation system was to make this possible.

Upon arrival at the disposal site, a three-transponder acoustic net was to be deployed by *R/V LULU*, *ALVIN's* support ship. The scientific team aboard the submersible *ALVIN*

would then locate a suitable waste package and its position within the navigation net would be carefully determined. After *ALVIN* returned to the surface, *R/V CAPE HENLOPEN* personnel would lower the lift cable with a clump weight and an acoustic relay transponder attached to the 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 aboard *R/V LULU* to track the lift cable position and instruct *R/V CAPE HENLOPEN* personnel in the maneuvering necessary to bring the cable clump within the required 100 meter distance from the selected drum (Figure 4). A description of the ALNAV navigation system is provided in Appendix I.

This planned approach was simple but imposed two requirements on the lift vessel. First, it had to have excellent slow speed maneuverability and station-keeping ability since once the lift cable clump was in position, the ship could not be allowed to drag it away. 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).

R/V CAPE HENLOPEN was newly constructed and although its Master was reasonably confident of its maneuverability, its station-keeping ability was unknown. Since a safety hazard would exist if the clump weight were to move while the submersible *ALVIN* was attempting attachment of the tag line, it was decided to eliminate the station-keeping requirement of *R/V HENLOPEN* by running all of the Kevlar lift line off the winch and attaching it to surface buoys while *ALVIN* was involved in the attachment phase (Figure 6).

Handling of complicated equipment strings was another area in which *R/V CAPE HENLOPEN* was untried. It was equipped with an adequate A-frame and deck crane plus two small capstans, but it lacked a secondary winch. Since an additional winch could not be guaranteed by the time of the planned operation, the equipment string was designed for hand-over-hand launch and recovery utilizing static stoppers. The weight of each segment was held to a value that could be brought on deck safely using the capstans. Figure 5 shows the resulting configuration for the lift line. Note that the 1500 pound (680 kg) clump weight is configured for release by the submersible once attachment to the target container is accomplished.

4.2 Recovery Operation

R/V LULU sailed from Woods Hole for the disposal site on 27 July 1976. Participants aboard included Robert Dyer, Office of Radiation Programs, EPA, Project Leader for the recovery operations, and Cliff Winget, Research Specialist, WHOI, *ALVIN* Group Expedition Leader. On the same date, *R/V CAPE HENLOPEN* sailed from Lewes, Delaware with Stephen Dexter as Chief Scientist, and Peter Colombo, 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

R/V LULU arrived at the site on 28 July 1976 and deployed a three-transponder navigation net. *ALVIN* dive number 676 commenced the following morning, and a suitable 80 gallon waste package was located shortly after reaching the bottom (Figure 7). The waste package was filled with concrete and half buried in the sediment. It showed no deformation due to hydrostatic pressure or impact with the bottom. The cable basket/harness lift line attachment device was deployed without difficulty (Figure 8), and the duration of the dive was spent collecting biological and sediment samples in the vicinity of the container.

At 1800 on the evening of 29 July 1976, *R/V CAPE HENLOPEN* took up position approximately 1 kilometer east of the selected target drum and lowered the Kevlar lift line with clump weight and acoustic relay transponder (see Figure 4) until the clump was approximately 75 meters above the bottom. Maneuvering runs were then made taking direction from the acoustic navigation team aboard *R/V LULU*. The limited weight of the clump in water coupled with the nearly neutral buoyance of the Kevlar lift cable made control of the cable end difficult, and acceptable placement of the lift line clump weight within 100 meters was not accomplished until approximately 0600 on the morning of 30 July, twelve hours later. By 0800 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 primary buoys to facilitate recovery operations.

The submersible *ALVIN* dove again at 0900 on 30 July 1976 carrying a 100 meter tag line to connect the waste package to the lift line (see Figure 6). Attachment to the lifting harness on the container proceeded smoothly and *ALVIN* was able to run the tag line between the waste package and the lift line, make the required connection, and finally detach the clump weight using the safety release hook without difficulty (see Figure 5).

Final hoist procedures were begun by *R/V CAPE HENLOPEN* personnel at about 0200 on 31 July 1976. The steel buoys were recovered and the Kevlar lift line fed back onto the trawl winch. The actual lift proceeded smoothly with the waste container reaching the surface at approximately 0800 on 31 July 1976 (see Figure 9). Some time was lost and extra effort was required due to the mismatch between the Kevlar line and the trawl winch level-wind mechanism. It was necessary to station personnel in the winch room to manually assist in obtaining a uniform cable lay on the drum.

The last phase of the operation involved recovery of the hardware at the end of the lift cable and finally bringing the waste package aboard. Figure 5 shows that the terminating hardware consisted of 2.5 meter long wire rope strings connected together with shackles plus oval connecting links. The 1500 pound (680 kg) clump anchor 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 located approximately 10 meters above the clump anchor. Above that, cast 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, which in turn, passed through a large trawl block at the top of *R/V CAPE HENLOPEN*'s A-frame.

The trawl winch brought the Kevlar aboard until the first bottom hardware connection

point was level with the main deck. At this point, a tag line was hooked into the oval connecting link and the lift continued until the connection was about to enter the trawl block. The hardware string lengths had been chosen such that when the upper connection reached the trawl block, the lower connection would be level with the main deck. This allowed hooking a static tag line secured to a bit on deck into the lower connecting link and transferring the load by paying out with the main winch. The main cable was then paid out further while the first tag line was used to manually pull the upper hardware string inboard and onto the deck where it was secured. The main lift line was then transferred to the top of the second hardware string and the process repeated.

This method allowed recovery of the hardware until reaching the tag line attached by the submersible between the clump weight and the waste package. This was 100 meters of 1 inch (2.54 cm) nylon without intermediate attachment points. The *R/V CAPE HENLOPEN* did not have a winch or capstan suitable for this line, therefore a less direct method was utilized.

The size of the trawl block at the top of the A-frame had been selected to allow the passage of the tag-line-to-lift-line attachment hardware. It was therefore 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 associated with the trawl winch. At this point, soft line stoppers were attached to the lift tag line at the main deck level and the load transferred to these. It was then possible to disconnect the Kevlar lift cable from the nylon tag line and lead the nylon to a set of bits. The remainder of the tag line was brought aboard hand-over-hand using the two available capstans in conjunction with a pair of line stoppers. The nylon tag line was continuously secured to the bits with minimum slack, thereby providing a method to hold the load should one of the stoppers slip.

Once the steel cable at the drum attachment device reached the level of the main deck, the Kevlar lift line was reattached and used to raise the container clear of the water (Figure 9). It was held in this position while the level of radioactivity was checked, handling tag lines were attached, and preparations for further containment in an overpack for transport were made on *R/V CAPE HENLOPEN's* aft deck. The aft deck was covered with a waterproof material elevated at the forward end and sides to contain drippings from the waste package as it was brought aboard. The overpack was placed in the center of this deck covering in a position allowing the waste package to be brought aboard and lowered directly into the pack by the ship's A-frame. Access to the stern of the ship was restricted to the minimum number of required personnel fully clothed in disposable oversuits, which were removed prior to leaving the stern area. During the operation, radiation levels were continuously monitored by a Brookhaven 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 Pacific Ocean Recovery

5.1 Equipment Design and Preparations

The success of the 1976 waste package recovery led to the planning of a similar operation to be conducted in 1977 at the Farallon Islands disposal area off the coast of San Francisco. This location consists of two subsites: site "A" at $37^{\circ}38'N$ and $123^{\circ}10'W$ with a water depth of 900 meters, and site "B" at $37^{\circ}37'N$ and $123^{\circ}18'W$ with a water depth of 1700 meters (see Figure 10). Waste packages were to be recovered from both subsites. The Canadian manned submersible *PISCES VI* with its support ship *R/V PANDORA II* was chosen for the operation, with the University of Southern California's *R/V VELERO IV* serving as the lift and recovery ship. Woods Hole Oceanographic Institution *ALVIN* Group personnel were retained as advisers, since the recovery method was to be similar to that used previously with the submersible *ALVIN*.

The characteristics of the submersible and support ship were such that Woods Hole personnel were able to provide waste package lift line attachment equipment identical to that used in the 1976 Atlantic Ocean recovery operation. *R/V VELERO IV* was equipped with a secondary winch for use during the hand-over-hand operations required in the final stages of recovery. Surface and submerged navigation was to be provided by outside contractors utilizing a Motorola Mini-Ranger system and a commercially available Ferranti ORE, Inc. long baseline acoustic system, respectively.

5.2 Recovery Operation

R/V VELERO IV departed San Francisco for the disposal site on 17 October 1977. Participants aboard included Robert Dyer, EPA Project Leader and Michael Smookler, Interstate Electronics Corporation, Cruise Leader. *R/V PANDORA II* with *PISCES VI* aboard departed the following day, arriving on station at approximately noon on 18 October 1977. Three acoustic transponders were deployed from *R/V PANDORA II* using the Mini-Ranger surface navigation system aboard *R/V VELERO IV* for positioning. It was hoped that once the bottom navigation system was deployed, *R/V PANDORA II* would be free to proceed to other areas of the disposal site for sample collection activities using the Mini-Ranger system for positioning. Navigation of *R/V PANDORA II* would be done relative to the acoustic transponder net and accurate surface fixes would not be required. Unfortunately, the acoustic navigation system failed to operate properly and the first *PISCES VI* dive for the purpose of locating a waste package for recovery was unsuccessful due to the lack of a bottom reference.

On 21 October 1977 *PISCES VI* again dove on the 900 meter subsite using an acoustic pinger deployed the previous night as a bottom reference marker. This dive successfully located waste packages, but without the acoustic navigation net, it would not be possible to navigate the lift cable into position near a selected drum. As an alternative, direct lift by the submersible was considered. The waste packages located during this dive were of a

Figure 10: Chart of Pacific Ocean Disposal Site

55 gallon drum configuration with an estimated weight of 875 pounds (397 kg), well within the 1500 pound (680 kg) payload capacity of *PISCES VI*. That evening, the *PISCES* crew reconfigured the submersible for a direct lift (Figures 11 and 12).

The Woods Hole cable 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 submersible. Once the lifting harness was secured to a selected waste package, the tag line was attached to the harness and the submersible surfaced with the waste container suspended beneath it. A second, short line was attached to the tag line at the release point beneath the submersible and lightly secured to a point which would be above water when the submersible reached the surface. This was an attachment point for *R/V VELERO IV*'s main lift line, to be used when transferring the waste package from beneath *PISCES VI* to the recovery ship.

PISCES VI was launched at 1035, 22 October 1977, for a recovery attempt and returned to the surface at 1530 with a 55 gallon waste package suspended below. *R/V VELERO IV* moved into position and its lift line was attached to the drum's tag line. *PISCES VI* then released the lift bridle tag line and the drum swung through the water from beneath the submersible to beneath the recovery ship. The remainder of the operation was straightforward due to the secondary winch aboard *R/V VELERO IV*, which was capable of handling the nylon tag line directly. Safety precautions taken on the recovery ship and the submersible were similar to those for the Atlantic Ocean 2800 m depth recovery in 1976 (Figure 13).

A second recovery attempt was to have been conducted at the 1700 meter subsite, but poor weather conditions, particularly dense fog, precluded further operations. *R/V VELERO IV* docked in San Francisco where the recovered package was prepared for delivery to Brookhaven National Laboratory 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 Atlantic Ocean Recovery

6.1 Equipment Design and Preparations

The second east coast recovery was to be conducted at the Hudson Canyon disposal site where water depths average 3800 meters (see Figure 1). The method to be used was similar to that of the previous year's successful west coast operation. The vessels employed were the manned submersible *ALVIN* and its mother ship *R/V LULU*, plus the waste package recovery ship *R/V ADVANCE II* operated by the Cape Fear Technical Institute.

Records indicated that the containers at this site were of the 55 gallon size and therefore were within *ALVIN*'s direct lift capacity, provided that certain non-essential equipment was removed to provide maximum payload. A lift line attachment point was added beneath the submersible, secured in place with explosive bolts for emergency release purposes. A short, stainless steel cable was run from the lift point, through a primary release explosive cable cutter to a pear link which was to be the attachment point for the drum tag line. A second line attached to this link ran up the side of the *ALVIN* submersible and was loosely secured to a point which would be above water when the submersible was on 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 waste package lift harness. This tag line and the lift harness were mounted on *ALVIN*'s forward equipment attachment frame which had been stripped of the hardware normally carried for scientific sampling (see Figures 14 and 15).

R/V ADVANCE II was equipped with deck gear superior to that of the two ships used in the past recoveries. The ship had a large stern A-frame with multiple blocks, a trawl winch and cargo boom located on the main deck, plus two large capstans and a secondary winch 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 drum from beneath the submersible. The trawl wire and additional nylon lines were also available for this purpose.

6.2 Recovery Operation

R/V LULU sailed from Woods Hole on 20 June 1978, and *ALVIN* dive numbers 812 and 813 were conducted at the disposal site on 23 and 24 June. Participants aboard included Robert Dyer, Office of Radiation Programs, EPA, Project Leader for recovery operations.

A suitable 55 gallon waste package was located on the second dive at a depth of 3970 meters. Its position was marked utilizing the ALNAV navigation system operated from *R/V*

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

LULU. The submersible *ALVIN* was configured for the direct lift recovery operation that evening by removing non-essential science support equipment, adding additional syntactic foam flotation material, and installing the releasable lift equipment described above. Additional payload was to be obtained by carrying one, rather than the usual two, observers during the recovery dive. Disposable ballast weights were attached to an auxiliary release assembly mounted on the unused starboard manipulator support bracket in order to compensate for the unusual buoyancy condition during descent.

ALVIN was launched for the recovery operation at 0812, 25 June 1978, and returned to the surface at 1455 with the waste package suspended beneath it. Two hours had been spent in the descent to the 3970 meter depth and the ascent with the suspended waste package had required an additional 3 hours. During the remaining time, the occupants of the submersible had relocated the selected waste package, attached the lift harness (see Figure 16), and finally attached the lift tag line to the harness. Transfer of the waste package to the *R/V ADVANCE II* lift equipment was accomplished by using a small boat to carry the nylon lift line from *R/V ADVANCE II* to the submersible *ALVIN* where it was shackled to the above-water attachment point by swimmers (Figure 17) .

Once completed, the slack was taken out of the line, swimmers checked for entanglements, and the waste package in the lift harness was released utilizing the explosive cable cutter. The ensuing movement of the waste package from under the *ALVIN* submersible to under the stern of *R/V ADVANCE II* occurred slowly with no visible shock loads.

The waste package was subsequently brought to the ocean surface with the tag line running through a center trawl block at the head of *R/V ADVANCE II*'s stern mounted A-frame 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 waste package lift 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. It was necessary to connect *R/V ADVANCE II*'s main trawl wire to the cable of the lifting harness, take up the load and remove the snap hook and *ALVIN* tag line. Once attached, the trawl wire was used for the remainder of the lift.

After clearing the surface, the drum was held outboard while smears were taken for radiation level determinations. While this was in progress, handling tag lines were attached and a jet engine case was moved into position on the stern for use as an overpack for transport. Once in place the A-frame was brought inboard and the waste package lowered into the case and secured with metal bands (Figure 18). The case was then sealed shut and purged with argon to retard corrosion. Safety precautions used throughout the operation were those outlined previously. Note the protective clothing worn by personnel working in the vicinity of the recovered waste package shown in 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 Conclusions

Each of the three recovery operations discussed in this report required two surface ships and a submersible with a total daily operational cost of approximately 30,000 1986 dollars. A single waste package was recovered during each expedition and at least one additional day would have been required for each additional package. The recovery techniques employed were similar allowing each operational team to learn from the experiences of the previous teams. The third recovery clearly presented the least difficulty despite the fact that the site depth and package weight were close to the *ALVIN* submersible's maximum ratings of 4000 meters and 1000 lbs. (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 in order to be deployed by a submersible. All of the objectives were met with the wire rope basket/harness attachment device which performed perfectly on all three recoveries. The only drawback to its use was the length of time required for the submersible to tighten the closing noose using the cable ratchet assembly and even this was small compared to the submersible's five hour descent plus ascent time for the deepest recovery (3970 meters).

Weaknesses of the recovery methods are the result of the overall operational complexity. Success was dependent upon too many factors, including proper coordinated operation of two ships and a submersible, both surface and submerged navigation systems and multiple lift devices. This level of complexity is not abnormal for operations involving work in the deep ocean, but it does decrease the chances for success, and the required knowledge plus attention to detail required to overcome it add to the expense. As an example, the 1976 recovery involved navigated lift cable positioning which required a special personnel team with members on both surface ships working for twelve hours. The following two recoveries did not use a surface lift cable, decreasing the complexity and increasing the chance for success.

Figure 18: Waste Package in Lower Half of Transport Overpack

8 Recommendations

Waste packages should be well labeled, standard configurations designed with consideration for the possible need for future recovery. Disposal operations should include verification of correct location and proper physical condition of packages having reached the sea floor.

The present technology level in the area of cable-controlled robotic undersea vehicles allows the construction of a special purpose recovery device capable of use with most reasonably sized oceanographic vessels. This device could conceivably be used to locate a suitable waste package, obtain sediment samples in the immediate area, take radiation level readings, and finally enclose the selected package in a container suitable for direct placement aboard the surface ship and transport to a shore site for analysis. Costs would be less than those of the methods described in this report since only one surface ship would be required. Around the clock operations could result in three to four waste package recoveries per day. The only major requirement would be a reasonable amount of planning and design effort prior to waste disposal operations to ensure that the waste packages or perhaps selected representative packages were suitable for recovery with this method.

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9 Appendix A

ALNAV Long Baseline Acoustic Navigation System

The ALNAV acoustic navigation system was developed at the Woods Hole Oceanographic Institution to provide a method for accurately navigating the submersible *ALVIN* relative to a fixed location on the sea floor. At the time, 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 was suitable for safety purposes, but it was not adequate to allow repeated returns to a given location on the sea floor during a dive or series of dives. One of the 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 could not exceed the accuracy of the ship's global navigation.

The bottom-referenced, long-baseline system overcomes this limitation and also provides an inherent accuracy increase due to the acoustic principles involved. The system utilizes a network of bottom-moored acoustic transponders. These 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 acoustic 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 receive 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 a specially-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 1% of water depth.

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