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THE B.A.P. PACOCHA (SS-48) COLLISION: THE ESCAPE AND MEDICAL RECOMPRESSION TREATMENT OF SURVIVORS

by

Claude Harvey, M.D.
John Carson, M.D.

Naval Medical Research and Development Command
Research Work Unit 63/13N M0099.01A-5012

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NAVAL MEDICAL RESEARCH AND DEVELOPMENT COMMAND
Research Project 63713N M0099.01A.5012

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SUMMARY PAGE

The Problem

At the request of the Peruvian Navy, a United States Navy Assist Team, consisting of two experienced Undersea Medical Officers, reviewed the medical response, rescue, evacuation, and recompression treatment following the sinking of the B.A.P. PACOCHA on 26 August 1988.

The Findings

Approximately half were rescued after immediate escape before the sinking with a 2-4 hour cold-water exposure. The other half were trapped for over 20 hours in the forward torpedo room after sinking. Escapees suffered decompression sickness and gas emboli after surfacing. Procedures and treatments were reviewed.

Application

Some observations are presented that might diminish morbidity and mortality in the future.

ADMINISTRATIVE INFORMATION

This research was carried out at the request of the Peruvian Navy and under Naval Medical Research and Development Command Work Unit 63713N M0099.01A-5012, "(U) Medical problems associated with pressurized submarine rescue." This special report was approved for release on 30 March 1989 and designated NSMRL Special Report SP89-1.

The B.A.P. Pacocha (SS-48) Collision: The Escape and Medical Recompression Treatment of Survivors

by

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ABSTRACT

At the invitation of the Peruvian Navy, a U.S. Navy team reviewed the circumstances surrounding the collision, sinking, and subsequent escape and rescue of members of the crew of the B.A.P. PACOCHA. Approximately half were rescued after immediate escape before the sinking with a 2-4 hour cold-water exposure, and the other half were trapped for over 20 hours in the forward torpedo room. They escaped by buoyant ascent, after having been subjected to pressure from partial flooding and air being introduced from the air banks. Escapees suffered decompression sickness and gas emboli after surfacing. The medical response, rescue, evacuation, and recompression treatment of survivors using all available equipment and personnel is reviewed. Some observations are presented that might diminish morbidity and mortality in the future.

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EXECUTIVE SUMMARY

A United States Navy Assist Team, consisting of two experienced Undersea Medical Officers, visited the Peruvian Navy from 31 January thru 2 February 1989 to review the lessons learned from escape and rescue operations following the sinking of the B.A.P. **PACOCHA** on 26 August 1988. This report summarizes the information available, discusses implications, and makes recommendations for consideration by both countries.

The B.A.P. **PACOCHA** was transiting to its home port on the surface, when it was struck on the aft, port quarter by the ice breaking bow of the **KIOWA MARU** at 1850 on 26 August 1988. No collision alarm was sounded and bulkheads were not sealed at the time of impact. The aft escape hatch, the bridge access hatch, the forward escape hatch, and the main induction valves were open at the time of impact. **PACOCHA** sunk to a keel depth of 140 feet in 5 minutes and the **KIOWA MARU** continued on to port, unaware of what it had hit. Twenty-three people escaped into the water as the boat sank. Three of these died of exposure prior to the arrival of help two and 1/2 hours later. Three people died in flooded compartments and the Captain of the vessel died in the sail while closing the bridge access hatch. Twenty-two people survived in the **PACOCHA**, ultimately retreating to the forward torpedo room as the atmosphere in the boat became contaminated. Pressure in the submarine was elevated from the start and later was calculated to have reached 54 feet of sea water gauge pressure over the next 17 1/2 hours. The United States fly-away McCann rescue system was activated, but aborted in transit when deterioration of the atmosphere within the **PACOCHA** led to a decision to use buoyant escape techniques. The escape, completed by the twenty-three hour mark, resulted in twenty of the twenty-two escapees developing symptoms of decompression sickness. All were ultimately treated with recompression therapy. One died, one is severely brain injured, and several have residual injuries from decompression sickness. Implications for procedures, training, support and equipment modifications are discussed in this report.

INTRODUCTION

The following narration of events was compiled from interviews conducted 31 January - 2 February 1989, with numerous parties, including Rear Admiral Guillermo Tirado, Commander of the Submarine Flotilla, five survivors who were trapped in the submarine, four divers involved in the escape, five physicians involved in the recompression treatments, and four physicians involved in subsequent hospital treatments. The members of the Assist Team from the United States were Captain C. A. Harvey, MC, USN, Commanding Officer, Naval Submarine Medical Research Laboratory and Commander J. F. Carson, Senior Medical Officer, Submarine Development Group One. Both are Undersea Medical Officers familiar with submarine escape and rescue techniques in the U. S. Navy.

Fluency in English was variable. Rear Admiral Tirado, a 1962 graduate of the U.S. Naval Academy, was highly fluent and most cooperative. He spent an entire morning providing a candid narrative of events as recorded in his investigation. Two of the divers and one of the physicians involved in the recompression treatment were able to converse in English, and two of the hospital physicians were also conversant in English. All others possessed little or no English capabilities.

Since neither of the interviewers spoke Spanish, much of the information was narrated through an interpreter. We were most fortunate in this regard to have the services of a Peruvian Medical Officer, LT Guillermo "Willie" Alexander Smith, who was highly fluent in English. Although he was not trained in Diving or Submarine Medicine, which might have helped us gain better information more quickly, he was interested, motivated, and did an outstanding job. We were most grateful for his services, without which we would not have been able to function or resolve conflicts in information. The combination of a language barrier, elapsed time since the accident and perhaps misinterpretation of statements may have produced errors in this report. If so, the team members apologize. Nevertheless there are valuable lessons and experiences to share with all who serve beneath the sea. It is in this spirit that this report is submitted.

NARRATION OF EVENTS

Friday, 26 Aug 88

1820 - Sunset.

1850 - Collision.

Following torpedo exercises, the **PACOCHA**, (Former **USS ATULE**, SS 403, transferred to Peru in 1974), was transiting to the Port of Callao on the surface with a 1900 hr ETA. The forward torpedo room, aft torpedo room, and bridge hatches as well as the main induction valve were open. Forty-nine people were aboard, including the Squadron Commander to conduct an operational readiness inspection.

The **KIOWA MARU**, A 412 ton Japanese fishing trawler was sighted by lookouts and by the Officer of the Deck prior to the collision. It apparently was "lit up like a Christmas tree and those on board had difficulty determining its bearing. The personnel of the **PACOCHA** felt they had the right of way and waited for the **KIOWA MARU** to maneuver, which it didn't. Last minute maneuvers by **PACOCHA** failed to avoid the collision which occurred at 1850 hours when the bow of the **KIOWA MARU** struck the **PACHOCA** in the aft port quarter (Appendix 1).

Damage was severe because the **KIOWA MARU's** bow was reinforced for ice breaking and had a sub-surface protrusion for that purpose. The **PACOCHA** was opened like a tin can. The ballast tank and fuel oil tank in the area of impact were ruptured, and a 2 meter by 10 centimeter split in the pressure hull resulted along the weld seam where the pressure hull widens aft of the ballast tanks (Appendix 1 and 2). Through this split, both fuel oil and water rushed into the "Control Cubico" or maneuvering room, the compartment just forward of the aft torpedo room. The watertight door between maneuvering and the aft torpedo room could not be closed because it was warped by the collision. The watertight door to the aft engine room was closed, however.

Unfortunately, the collision alarm was never sounded. Whether individuals on the bridge failed to sound the alarm or the alarm was not operational is unclear. Either way, the result was the same. Individuals forward of the "Control Cubico", other than those on the bridge, were not aware that there had been a collision. Immediate word was passed that there was a fire in an engine room. Individuals began moving to the scene, both through the interior of the ship and via the forward hatch, moving aft topside. The true nature of events was revealed almost immediately, however, when **PACOCHA** began to assume an up angle.

1850 - 1853 Surface Escape.

As PACOCHA's stern sank, crew members exited from the bridge hatch and from both the forward and the aft torpedo room hatches. Before PACOCHA sank, a total of twenty-three personnel escaped into the sea, most, but not all, with life vests or some form of buoyancy device. Some used Steinke hoods as buoyancy devices. Fortunately, surface conditions were calm with less than two foot seas, allowing twenty of the twenty-three to survive. Three deaths resulted from drowning or exposure in the 14 degree Celsius (57 degree Fahrenheit) water.

One of the three individuals who perished in the water was responsible for closing the main induction valve. He failed to do so before abandoning ship. Hence, as soon as PACOCHA's induction mast was below water both engine rooms also rapidly flooded. Fortunately, the watertight door between the forward engine room and the aft battery compartment had been secured. Otherwise, the entire ship might have flooded.

Three crew members, a lieutenant, a chief, and a petty officer, were trapped in the flooded compartments. Their bodies were recovered three weeks later.

The Captain of the ship, Commander Nieva, lost his life securing the bridge access hatch. Divers located his body the following morning inside the deck access door to the sail.

In the forward torpedo room, Lieutenant Cotrina, the senior survivor aboard, secured the forward torpedo room watertight door and began to blow air to the compartment. He then went to the forward torpedo room hatch to secure it. Instead, however, he had to force the hatch open to free a sailor whose leg was caught as the hatch fell closed due to the 40 degree up angle PACOCHA assumed before sinking below the surface. As the PACOCHA began her slide to the bottom, water rushed in the forward hatch, washing Lieutenant Cotrina down the ladder, but fortunately, shortly afterwards, forcing the hatch closed. Lieutenant Cotrina considered this a miracle.

1855 - PACOCHA: On the Bottom.

Survivors estimate the time lapse between collision and settling on the bottom to be no more than five minutes.

LT Cotrina secured the blow to the forward compartment which he estimated lasted forty seconds from the time the forward torpedo room hatch closed until the blow was secured. Because of the pressure created, the water-tight door leading aft could not be opened initially. When tried later it opened, suggesting that pressure equalized slowly, probably through valves and vents rather than across the door.

Meanwhile in main control, the ballast tank blow was secured. A strong odor of chlorine from the aft battery compartment prompted a check of all valves and vents to be sure water was not entering this, or any other compartments. The aft battery was disconnected and this compartment was sealed from the rest of the forward compartments.

Keel depth was noted to be 140 feet with a 9 degree up angle.

1900 - Scheduled Return to Port

Initially, the failure of PACOCHA to return to port on time was not of great concern to watch personnel. She had been in radio communication less than an hour previously. She had surfaced and was transiting to port. But as time passed, concern grew, especially after several attempts to make radio contact failed.

Other ships and the Maritime Authority were contacted to see if anyone knew of PACOCHA's whereabouts. At first no one had any information. Then a radio conversation between the KIOWA MARU and its agent in Lima, in which the KIOWA MARU stated that it may have hit another vessel, was passed to watch personnel.

2002 - Emergency Declared.

Maritime authority boats were dispatched to search along PACOCHA's route. The tug JENNIFER II, was sent to the KIOWA MARU to investigate.

2020 - Admiral Tirado Arrived at the Callao Naval Base and Assumed Command.

Following notification and arrival at his headquarters, Admiral Tirado dispatched the submarine DOS DE MAYO to search. As yet there was no hard evidence that PACOCHA was involved in a collision, let alone that she had been sunk.

2030 - PACOCHA: Released Messenger Buoy.

In addition to releasing their messenger buoy, those in the forward compartments of PACOCHA attempted to call aft compartments on the sound powered telephone. There was no response.

2050 - Collision Confirmed by JENNIFER II

Arriving at the KIOWA MARU, the personnel of the JENNIFER II had difficulty communicating with the Japanese crew. Initially, they were distracted from discovering the collision by requests to take one of the Japanese in SCUBA to the bow of the ship to investigate for damage. Eventually, they learned from a Peruvian fisherman, accompanying the Japanese as a guide, that there had been a collision with something. On the way into port, the

KIOWA MARU had apparently gone a few hundred yards after the collision before coming to a stop in the water and then continuing into port unaware of what she struck.

2050 - Recall of Divers Commenced.

2050 - PACOCHA: Fired a Red Distress Flare.

As the JENNIFER II was reporting the collision on their radio, the collision area was illuminated by the first red distress flare fired from PACOCHA. The flare revealed many of the survivors in the water--but no boat. The fate of PACOCHA was now known.

2051 - Surface Survivors Rescued.

By 2100, many small boats from other ships were involved in the rescue effort. By 2240, twenty were rescued and three bodies were removed from the water. The last crew members rescued spent almost four hours in 14 degree Celsius (57 degrees Fahrenheit) water. Since only twenty-three crew members had been accounted for, surface search for survivors continued through the night. Those on the surface had no way of knowing that all remaining crew members were still aboard PACOCHA.

2100 - PACOCHA: Roll Call.

Survivors in the PACOCHA held a meeting in the forward torpedo room. A roll call was taken which revealed twenty-two survivors. Of these, there were four officers, four chiefs, and fourteen junior enlisted personnel.

Crew members were instructed to minimize activity. Many were wet and changed into dry clothes which were obtained by opening lockers of crewmen normally berthed in the surviving compartments. Temperature in the boat was 21 degrees Celsius (70 degrees Fahrenheit). Contrary to expectations, the temperature actually rose over the next 24 hours to 25 degrees Celsius (77 degrees Fahrenheit), in spite of an estimated water temperature at depth of 11 degrees Celsius (52 degrees Fahrenheit).

2120 - PACOCHA: Fired Another Flare.

This flare led searchers to PACOCHA's messenger buoy.

2131 - Messenger Buoy Located

Unfortunately, the messenger buoy on this class of submarine did not have a telephone, so communication could not be established with PACOCHA. Those on the surface realized, however, that someone was probably alive to release the buoy and fire the flare.

2145 - PACOCHA: Steinke Hood Training.

Training in the use of the Steinke Hood for escape was conducted. Crew members had received very little training in the use of the Stienke hood. The Peruvian Navy, like the U.S. Navy, stopped formal in-water escape training from depth several years previously. This change in Peru came after a sailor died during a training exercise.

2240 - The Last Survivors were Rescued from the Water.

Twenty-three personnel were accounted for. Unbeknown to the rescuers, the remainder of PACOCHA's crew were in the submarine.

2250 - PACOCHA: Chlorine Gas.

The smell of chlorine gas in main control prompted another assessment of the boat's condition. A vent valve was found that had not been tightly closed, and more water had seeped into the aft battery compartment. All lithium hydroxide canisters were brought forward, and the survivors sealed themselves in the forward torpedo room.

2330 - PACOCHA: Settled for the Night.

Two canisters of lithium hydroxide were opened and spread on upper bunks. They recognized that spreading the lithium hydroxide on lower bunks would have been more effective, but the lower bunks were damp. The crew was put to bed.

2330 - Admiral Anderson Notified of Potential Need for a Rescue System.

2345 - The Director of the Naval Hospital was Alerted that Help Would Be Required.

2400 - Survivors Ashore.

By 2400 all twenty survivors and three bodies had been brought ashore. Survivors were taken to the nearby Naval Hospital. Although all were suffering from hypothermia, none had significant injuries. No subsequent deaths occurred among this group.

Saturday, 27 August 88

0000 - Divers Arrived on Scene.

By midnight an assortment of vessels were on the surface including the submarine, DOS DE MAYO; a torpedo retriever; a floating crane; and several small craft.

Only eight divers were initially located. Locating divers during their off-duty hours was hampered by the lack of telephones in many of their homes. They were now on scene ready to begin diving in SCUBA gear. Depth to the deck of the ship was between 125 feet aft and 110 feet forward, with the ship variably reported as having between a nine and fifteen degree up angle. The first team of divers followed the messengers buoy's line which had played out to a significant distance. Since it was not located directly over PACOCHA, a second line was tended straight down to the sail. The divers tapped on the hull and received a response from the forward compartment of the boat. Unfortunately, they were unable to interpret the tapping initially, since they were unfamiliar with the code used.

0040 - Request for U.S. Navy Assistance.

Admiral Tirado called Captain Schillingsburg, U.S. Defense Attache, to request rescue assistance from the U.S. Navy. Short delays were encountered establishing communication between Admiral Tirado and Captain Schillingsburg and between Captain Schillingsburg and the Office of the Chief of Naval Operations (CNO).

Although Captain Schillingsburg did not have a file on the agreement between Peru and the U.S. Navy to provide rescue assistance, the CNO watch officer was familiar with the agreement.

0100 - PACOCHA: Messages Were Sent to the Rescuers on the Surface that the Survivors Should be Able to Survive for 48 hours.

0200 - PACOCHA: Reassessed the Boat's Status.

Three volunteers donned OBA's and walked through compartments as far aft as main control. The aft battery compartment was noted to have water over the deck, so it was not entered.

0200 - Salvage Air Connections.

Personnel ashore including several divers studied the salvage air connections on PACOCHA's sister ship, LA PEDRERA. Salvers discovered that they did not have salvage air hoses or fittings. Ultimately, MK V diving system umbilicals were used with fittings manufactured during the night on two frigates. (MARK V Diving hoses are negatively buoyant, 1/2 inch inner diameter, 600 psig pressure rated hoses, U.S. MIL-H-2815).

0227 - Communications Established.

After two frustrating hours, improved communications with PACOCHA were finally established using the signal ejector to pass written notes to the divers. This pair of divers, the last of the initial group of eight, surfaced shortly thereafter. Each diver made one SCUBA dive, working in pairs, in wet suits to 110 feet for 20 minutes with a 3 minute decompression stop at 10 feet. None of the divers developed decompression sickness.

0350 - U. S. Navy Rescue System.

Word that the U.S. Navy was sending its rescue system brought great relief to those in charge of the rescue operation. Unfortunately, over the next few hours the estimated time of arrival of the rescue system shifted steadily to a later arrival time.

0420 - PACOCHA: Fired a Yellow Flare.

Not having had any communication from the surface for approximately two hours and unaware that there were currently no divers available, PACOCHA fired another flare. Yellow was picked so as not to give the impression that something new was seriously wrong--they just wanted to express concern that they had not heard anything in a couple of hours.

0440 - PACOCHA: Fire in Control.

Although details were not clear, a small electrical short/fire occurred in main control. Fortunately it was brief and self-extinguishing, but it was a new cause of concern for their atmosphere. Should there be a fire in their compartment, only carbon dioxide extinguishers were available.

0500 - Diving Resumed.

A new group of divers arrived on scene in the early morning. Ashore, they had reviewed salvage connections, escape trunk configuration, and other details on the PACOCHA's sister ship, LA PEDRERA. Shortly after the divers went to work, they discovered and recovered the body of PACOCHA's Commanding Officer, Commander Nieva, just inside the deck access door to the sail superstructure.

0600 - PACOCHA: Reveille.

Breakfast. Utilizing the signal ejector, communication was passed that the crew was in good spirits with enough air to last for seventy-eight hours based on calculations of available oxygen and lithium hydroxide. they also had adequate supplies of water, but no food after eating what little they had, including cake, for breakfast.

A heavy black cloud was noted to be rising from below the deck in the forward battery compartment. No one entered this compartment again. Two more canisters of lithium hydroxide were opened and spread on the upper bunks. Later in the morning another four canisters were opened. Approximately twenty canisters were unopened. One 8 cubic foot oxygen cylinder was bled into the compartment; three oxygen cylinders were left unused.

0630 - PACOCHA: Escape Training.

Information on the use of the escape trunk and the Steinke Hood was passed from the surface. The crew was divided into five groups and one member from each group trained in the operation of the escape trunk. Groups were arranged by seniority, with one officer in four of the five groups, and by other factors such as swimming ability and self confidence.

0645 - PACOCHA: Survivors Identified.

Via message, PACOCHA informed those on the surface that there were twenty-two survivors.

0730 - U.S. Navy Rescue System.

A message was sent to PACOCHA informing them that the fly-away rescue system was on the way from the U.S. This provided a visible boost to morale among the crewmen.

0950 - PACOCHA: Atmosphere Deteriorating.

LT Cotrina became increasingly concerned about the submarine's atmosphere when he noted that the crew was becoming listless, agitated, and hyperventilating. The lithium hydroxide did not seem to be doing the job. Therefore, he spread four additional canisters. Unfortunately the boat's only atmosphere monitoring equipment was aft in the flooded compartments. Their only light, the red emergency light located at the bottom of the forward ladder, was periodically flickering on and off, and the beam from their only battle lantern was steadily growing weaker.

0950 - Permission to Escape.

When Lt. Cotrina requested guidance, Admiral Tirado granted permission for the senior man onboard PACOCHA to use his best judgment to decide if and when escape should be executed because of deteriorating conditions.

1000 - PACOCHA: Decision to Execute Escape.

The crew met and the decision to escape was unanimous with one exception. One of the lieutenants voiced his opinion against escape for various reasons. If he had to escape, he wanted the divers to provide SCUBA tanks since he had been trained in SCUBA. The senior officer placed him in the first group of escapees. Hence the first group to escape was a group of four, composed of two officers and two enlisted.

1130 - Salvage Air.

Divers completed connecting high and low salvage using Mark V diving umbilicals for hoses and the manufactured fittings. The high salvage was connected to air banks on the submarine, ABTAO. These banks were charged by thirty-five year old, oil lubricated compressors. There are no filters on the system, and air samples of the air banks have never been taken. Lieutenant Cotrina briefly opened an air valve from PACOCHA's air banks to the compartment to help circulate the air. He may have done so on other earlier occasions as well.

1130 - PACOCHA: Escape Group One (Appendix 3)

During escape training, crew members decided to inflate their Steinke Hoods in the compartment before entering the escape trunk. For reasons that are unclear, they elected to use the Steinke Hoods as a flotation device, but not to enclose their heads in the hoods. One member of this group, Chief Monzon, did wear the hood. He was to be the third most seriously injured of the twenty-two escapees. After inflating the escape devices, the four entered the escape trunk (Appendix 4) and controlled flooding and pressurizing from inside the trunk. The water flooding the trunk was so cold that the escapees were sure they would die. They were all extremely frightened. After the side access hatch was opened, they spent at least ten minutes arguing over who would exit first. Finally LT Gomez, the senior man, ducked under and began his ascent, he was followed in turn by Chief Monzon and Petty Officer Reyes.

LT Gomez described how he began blowing out, but fearing he would not have enough air to reach the surface, he held his breath for a moment, then resumed breathing out again. He felt that his lungs were empty on arrival at the surface. After being on the surface for two or three minutes, he noted that his chest and neck felt "puffy". He described what could be interpreted as crepitus in his neck. Not long thereafter, he developed considerable pain in both shoulders.

Both enlisted crewmen also surfaced and initially seemed to be in good condition. After several minutes, however, they too became symptomatic. They became disoriented and unsteady, and developed pains and shortness of breath.

The fourth member of the group, however, failed to surface. Since those on the surface had been told to expect four in the first group they began to search but held little hope for the fourth escapee. While they searched, those in the forward compartment drained and opened the escape trunk. They found the fourth member of the team alive and well, still in the escape trunk.

1215 - PACOCHA: Escape Group Two. Lieutenant Nieri and Three Enlisted Personnel

This group completed their escape by 1225 hours without serious incident. Following an indeterminate delay, Lieutenant Nieri and possibly others in this group were flown by helicopter to the recompression chamber. Proper advice was given by Admiral Tirado, so that the helicopter flew low over the water. Further delay occurred before this group was recompressed, as the one usable chamber was in use.

Immediately after the second group surfaced, air was supplied through the high salvage connection. Aboard PACOCHA, water came from the line since it had not yet been blown dry. The high salvage was immediately secured from inside the ship and never reopened according to the senior officer on board, Lieutenant Cotrina. Low salvage, as best can be determined, terminated above the surface of the sea and was open to the atmosphere. It originated below the surface of the water in the bilge, and thus was filled with sea water to a depth equivalent to the pressure in the boat.

1230 - Escape Group 3. Five Enlisted Personnel.

All five of the survivors in this group completed an uneventful escape by 1240. Unfortunately, after this group left the escape trunk, the outer escape hatch cold not be closed from inside the submarine. When the crew attempted to drain the trunk, sea water continued to flood into the submarine until the valves were secured. Attempts to drain the trunk were aborted when seawater had filled the bilge to the just below the deck, thus further increasing the pressure in the boat.

After their plight was communicated to the surface, divers were sent to investigate. Apparently one or more of the hatch's dogs were obstructing closure. The divers eventually freed the obstruction with a large wrench.

1500 - Escape Group 4. Four Enlisted.

This group made an uneventful escape by 1515. On reaching the surface at least one of them was transported to the shore recompression facility by helicopter.

1615 - Escape Group Five. Lieutenant Cotrina and Two Non-swimmers.

Survivors in this group made an uneventful escape by 1625. By this time, a recompression chamber was on scene on the floating crane along with two medical officers. All three in this escape group were recompressed within five minutes of surfacing.

1710 - Escape Group 6. Lieutenant Lindley, Chief Bendezu and Petty Officer Grande.

After the fifth group left the escape trunk, divers placed a set of SCUBA bottles in the trunk. Whether this was in response to requests by Lieutenant Lindley is not clear. Possibly it was done because of increasing concern that the atmosphere was becoming contaminated. Whatever the rationale, the final three escapees spent between one-half and one hour breathing from the SCUBA bottles before escaping at 1805. The exact time of entering, flooding, and pressurizing the escape trunk is unknown.

During this time, personnel topside were again becoming apprehensive. Investigating divers were present when all three escapees simultaneously emerged from the top escape trunk hatch. Why they didn't use the side hatch as had the rest of the escapees is unclear.

Since the chamber at the scene was occupied, these individuals were transported by boat to the shore facility. About an hour and a half lapsed between surfacing and recompression, apparently because no chamber was available. Unfortunately one of the three, Petty Officer Grande, developed such severe decompression sickness, possibly combined with gas embolus, that he died during recompression treatment.

DISCUSSION

Survivability in a disabled submarine depends upon many factors including oxygen levels, carbon dioxide levels, toxic gases, hypothermia, food, water, and atmospheric pressure in the submarine.

Food and water is rarely a factor which will limit survivability, as evidenced in this case. Toxic gases may have affected survival time. Whether significant amounts of chlorine gas had found its way into the forward compartment is unknown but the survivors, as a group, did not report lung irritation as a major complaint. Low oxygen levels may well be a factor in survivability, but usually not the limiting factor. High oxygen partial pressures can become toxic but it has been well demonstrated that humans can survive for at least 30 days in compressed air at 60 fswg. Thus that was not likely to have played a part in this scenario. The presence of other toxic agents in the air used to pressurize the compartment initially is possible but probably not as important as the ultimate carbon dioxide accumulation. Usually the limiting factor, especially if the submarine is pressurized, is elevation of the carbon dioxide level rather than hypoxia or other contaminants.

In a compressed air environment without replenishment, the partial pressure of carbon dioxide reaches critical levels before the oxygen partial pressure is significantly depleted and requires supplementation. LT Cotrina obviously understood the need to circulate and mix the air in the compartment to maximize mixing of the oxygen released from storage bottles and to enhance carbon dioxide removal by the movement of air across the Lithium Hydroxide. Unfortunately his resources for circulating the air were limited and he had no equipment to monitor the effectiveness of his efforts at atmosphere maintenance. It is possible that the small fire at 0440 hours in Main Control and the black smoke noted above the forward battery well at 0600 may both have been partly related to the increased partial pressure of Oxygen and the related increase in fire hazard inherent in a compressed air environment. A release of stored energy from the forward batteries from a battery fire might partly explain the rise in temperature within the PACOCHA from 21 degrees to 25 degrees Celsius. Oxygen was apparently being added to the atmosphere at a rate calculated to match oxygen utilization by the survivors. Thus the atmosphere in the compartments should have approximated the oxygen content of compressed air. The amount of Lithium Hydroxide spread out was, in retrospect, apparently insufficient to keep up with the metabolic production of carbon dioxide by the survivors. it is probably wise to spread out as much carbon dioxide absorbent as surface areas will permit right from the beginning when trapped in this situation. Elevation of atmospheric pressure can multiply the physiological effects of the component gases. Addition of uncontaminated air will not change the partial pressure of Carbon Dioxide or any other component previously present in the compartment. Elevated pressure, however, will not significantly affect the rate at which the partial pressure of Carbon Dioxide in the compartment climbs as people breathe. Accumulation of Nitrogen in body tissues will occur at fairly predictable rates related to the partial pressure of Nitrogen, so that when escape or rescue occurs the survivors may develop decompression sickness.

PRESSURE IN THE DISABLED SUBMARINE

Exact internal pressures and durations of those pressures in the forward torpedo room are unknown. Preparations were made from the beginning to mobilize all recompression chambers and personnel in the area for whatever contingencies developed. Certain information is now available allowing extrapolations and calculations to be made to estimate the variables of pressure and time.

a. As PACOCHA sank, water began to pour into the aft compartments of the boat via the rent in the pressure hull, the main induction valve, and the aft escape hatch. The water-tight door between the forward engine room and aft battery compartment was closed early in the flooding before the forward hatch was closed. Thus flooding and attempts to pressurize the aft compartments probably contributed very little to pressurization of the forward torpedo room.

b. LT Cotrina freed a man's leg from the side hatch of the forward escape trunk and attempted to close it as the boat sank. However, as the boat sank, water entering the hatch swept him out of the escape trunk before he could finish closing the hatch. LT Cotrina had ordered a high pressure blow in the compartment as water came in and this lasted for 1 to 2 minutes before the increasing angle off the boat slammed the hatch. The blow then continued for about 40 seconds until it was secured after it was obvious flooding had stopped. Thus, pressure in the compartment was increased above 1 atmosphere from that time on.

c. One 8 cubic foot Oxygen bottle was vented into the compartment during the time the men were trapped. Since the Carbon Dioxide absorbent (Lithium Hydroxide) was apparently not functioning well, the combination of unused Oxygen valved in plus the unabsorbed Carbon Dioxide produced may have contributed a small component to a pressure increase in the boat.

d. High and low salvage connections (Appendix 5) were completed at 1130 hours on 27 August, some 16 1/2 hours after the sinking. However the lines were flooded when connected and naturally sent a stream off water into the boat when pressure was initially applied to the high salvage line. The men in the compartment then secured the valve on that connection and it was never opened again. The low salvage line was underwater in the compartment and, although it apparently remained open at the surface, obviously remained filled with water to a height in the hose equal to the internal pressure in the boat. At that point the hose either collapsed from external water pressure, (It was not an armored hose), or remained open and filed with air the remaining distance to the surface. In either condition this did not allow air pressure to vent to the surface. Had either line been dry and open between the compartment and the surface, pressure in the compartment would have fallen to 1 atmosphere. Thus the high and low salvage connections apparently did not contribute to any pressure changes in the compartment. Considering the number of cases of decompression sickness that developed when the escapees reached one atmosphere of pressure on the surface, it is fortunate that such a pressure reduction did not develop in the boat when the hoses were connected.

e. The survivors cracked the valves from PACOCHA's air banks to circulate the air in the compartment on at least one occasion and perhaps more often. This also contributed to increasing the compartment pressure.

f. The flooding and subsequent draining of the escape trunk (Appendix 4) during each of the first five escape evolutions added water to the internal volume of the forward torpedo room and that further increased the pressure. This effect was accentuated following the third group of escapees when the side hatch did not close properly and a large volume of water entered the boat when drain down of the escape trunk was attempted.

g. Four hours after the sinking the survivors noted that an incompletely secured vent valve had allowed water to flood the battery well in the aft battery compartment. This volume of water also increased the internal pressure in the forward compartments.

h. It was noted that initially, after pressurization of the forward torpedo room, the water-tight door leading aft to the forward battery compartment would not open. Later the pressure apparently equalized between the compartments and the door could be opened. It is not clear whether pressure leaked from the forward torpedo room into the aft spaces or whether pressure increased in the aft spaces by some other mechanism.

These factors were recognized by the survivors, but there was no recall of a gauge or manometer showing the actual pressure in the forward compartment. However, during conversations with LT Cotrina, who pressurized the escape trunk for the first four groups that escaped, one additional important fact materialized. When the trunk is pressurized to equalize pressure with the surrounding water, in order to open the side escape hatch, air pressure is supplied from within the submarine. There was a pressure gauge on that line (Appendix 4) and it reads pressure in the line relative to that surrounding it in the boat. Since the escape trunk was at about 110 feet of sea water gauge (fswg) deep, it should have taken some 48.9 pounds per square inch gauge (psig) of pressure to equalize, assuming the boat were at surface pressure.

(Assuming 33 fswg = 1 atmosphere of pressure = 14.7 psig)
(110 fswg divided by 33 ft = 3.33)
(3.33 times 14.7 psig = 48.9 psig)

LT Cotrina, however remembered that the gauge was showing only 24 to 25 psig. A bit of additional calculations show that there may well have been approximately 54 feet of pressure in the boat at the time of the first escape.

(25 psig divided by 14.7 psig = 1.7 atmospheres)
(1.7 times 33 feet = 56 fswg of pressure needed to equalize)
(110 feet - 56 feet = 54 fswg of pressure in the boat)

The duration of this pressure is not clear, but certainly the incidence of decompression sickness (a minimum of 20/22 certainly indicates the pressure calculated above may be reasonable at the time of the escape evolutions. The historical events suggest an elevated pressure in the compartment from the first few minutes as the submarine sank with at least some minor step increase as events transpired over the remaining hours of their entrapment.

Work in the United States and England on pressurized escape and rescue in recent years has led to information from which guidelines for escape and rescue in this type of situation have been recently formulated. The time limit for "No decompression" exposure at 54 feet is 60 minutes as set forth in the U.S. Navy Diving Manual (Appendix 6). Thus after 1 hour at 54 feet, an increasing decompression obligation had been incurred, whether they escaped or were rescued. Further, the additional exposure to 110 fswg pressure followed by rapid decompression during the escape procedure made the risk of decompression even greater. Recent recommendations derived from British and U.S research show that at a depth of 110 FSWG, increasing exposures to pressures in excess of 1.7 atmospheres of pressure absolute (1.7 ata = 23 fswg) within the boat make it unsafe to escape rather than await rescue (Appendix 7). The lack of guidelines and absence of a pressure gauge to show internal pressure within the submarine made those within the submarine, as well as those on the surface, unaware of the increasing hazard during buoyant escape as time passed. While the possibility of gas embolism had been anticipated, certainly no one on scene or in Peru had the information to anticipate the number and severity of decompression sickness cases that were to develop after the otherwise successful escapes.

ATMOSPHERE REPLENISHMENT VIA SALVAGE CONNECTIONS

The amount of air that can be supplied to a submarine via the salvage connections is determined by the pressure and volume of air available, the diameters of the pipes and hoses, and by the ability of the hoses to resist collapsing from external water pressure.

But for a stroke of fate, rescuers might have seriously compounded the problems by pressurizing PACOCHA to a pressure equivalent to her keel depth or by filling the compartment with potentially contaminated air.

The high and low salvage were connected by divers (Appendix 5). Divers must swim down holding the distal ends of the hoses with the hoses full of water to maintain negative buoyancy and ease handling problems. The hoses were not normally blown dry prior to connection. Thus, although unexpected by the PACOCHA crew, seawater showered into PACOCHA when the high salvage valve was opened and air pressure applied from the surface. In retrospect, this was fortuitous, as it caused those inside to immediately shut the valve. If they hadn't, one of two potentially disastrous events could have occurred. First, since the low salvage line was open to atmosphere at the surface end and the other end terminated in the bilge, which was full of water, a water column equivalent to the pressure in the boat was created in the low salvage hose. It functioned like a manometer. If the high salvage air supply had been left open, pressure would have gradually increased in the boat and the water would have risen in the low salvage hose to a maximum height of the keel depth, or 140 feet until water in the bilge was blown out of the boat. Pressure in the boat would then have been equivalent to the pressure at 140 feet of sea water (62 psig). If the high salvage was then closed at any time during this dewatering, the crew would have been subject to this elevated pressure until escape or rescue occurred. At a minimum, they would have been exposed to this pressure for a considerable period of time while the significant quantities of bilge water were blown through the low salvage hose.

On the other hand, if the high salvage valve had been left open, when the bilges had been blown dry, air would have passed from the submarine through the low salvage at an uncontrolled rate and the boat would then have undergone rapid decompression either to surface pressure or until the 110 fswg water pressure external to the boat overcame the stiffness of the diver hoses employed and began to collapse the exhaust hose, thus establishing some new residual pressure level in the boat. If this new pressure level were sufficiently lower than the previous presure in the boat, the change could have precipitated decompression sickness for those inside, just as escape to one atmosphere ultimately did.

It is likely that the exhaust hose employed was resistant enough to remain open from the surface to 110 fswg and this would have been a real possibility. Had the pressure within the boat not been significantly elevated and a need existed to provide ventilation through the salvage system, the usual way of connecting the salvage hoses could perhaps have been reversed. The low salvage line cold have been connected to the air supply and the high salvage line opened to surface pressure. The value of this approach is tempered by the possibility of some form of toxic aerosol of contaminants forming as air bubbles through the water in the bilge. The attachment of an armored hose or extension pipe to the bottom end of the low salvage pipe in the boat, with its open end above the bilge water line, would allow ventilation of the boat by conventional salvage connections. The same result would be achieved if the low salvage lines were equipped with a "ventilation" valve nigh in the compartment to allow water to drain out and air to enter. Such a valve, if sufficiently adjustable to control flow rates, could also be used to selectively control decompression rates from within the boat once an external hose capable of resisting the water pressure was connected and led to the surface. No additional pressurization should occur, since little water would have to be blown from the lines if the valves were opened and water allowed to drain out of the lines before pressure was applied to the high salvage line.

The salvage hoses provided were rated at 600 psig. The air flow necessary to provide the absolute minimally adequate air flow to control carbon dioxide levels in a compartment (Assuming good mixing) is 2 standard cubic feet per minute (scfm) per man. Four scfm would be much more desirable to assure keeping the carbon dioxide below 1.5% surface equivalent. The air flow is independent of the volume of the compartment, and assumes good mixing. A few calculations show:

$$\frac{54 + 33}{33} \times 2 \times 22 = 116 \text{ scfm} = \text{Air flow required for 2 scfm/man}$$

$$\frac{54 + 33}{33} \times 4 \times 22 = 232 \text{ scfm} = \text{Air flow required for 4 scfm/man}$$

No figures are available for the manifold pressures and volumes available or for the hose lengths and flow rates that could have been achieved through the 1/2 inch hoses. However a significant ventilation through the salvage lines is possible.

Before a supply line is pressurized and before an exhaust line is opened to the atmosphere, it should be determined whether there is an elevated (Above 1 ATA) pressure in the boat. If there is, the valves must be operated so as to provide a controlled vent of the compartments without increasing or decreasing the pressure until proper guidance for the rate of decompressing the compartment is provided to the rescue team. The decision must then be made whether to decompress in the submarine before escape or rescue is attempted, or after escape or rescue. This is ultimately based on surface support capabilities, habitability, and the physical condition of the crew.

Compressed air from old, oil lubricated compressors may be breathable at atmospheric pressure without causing undue short term toxicity. At elevated atmospheric pressure, however, the same gas may be toxic to those breathing it. At PACOCHA's ultimate internal pressure, in retrospect now estimated to be between one and two atmospheres gauge pressure (2-3 ATA) at the time salvage air was connected, and possibly higher later in the day, toxic levels of certain gasses, especially carbon monoxide, might have been present. Such contaminants might have further jeopardized the crew if introduced from the salvage air connections during further pressurization of the PACOCHA. Everything considered, LT Cotrina probably made the best possible decision in securing the high pressure salvage line when he did.

CARBON DIOXIDE REMOVAL WITHIN THE SUBMARINE

An increasing Carbon Dioxide level was most likely the primary cause of the deterioration of the atmosphere on PACOCHA. Symptoms of agitation and hyperventilation are common when Carbon Dioxide is elevated. As pressure in the boat increased, the ill effects of Carbon Dioxide would be multiplied. Carbon Dioxide is produced at a rate of approximately 0.1 pound per man per hour. Therefore, in PACOCHA's forward compartment, 2.2 pounds per hour were being produced. Each Lithium Hydroxide canister contains 6.3 pounds of Lithium Hydroxide, capable of removing 5.8 pounds of Carbon Dioxide under optimal conditions. Spread on bunks, especially upper bunks in compartment with poor air circulation, scrubbing capability would be much decreased, and with the heavier Carbon Dioxide building up near the deck. The Lithium Hydroxide aboard PACOCHA was extremely old, having been provided with the boat when it was transferred to Peru.

Under these circumstances, allowing a loss of efficiency of 25%, a canister could remove 4.4. pounds of Carbon Dioxide, the equivalent of two hours of production, is extremely optimistic. Overall, eight canisters were opened, enough to maintain levels for sixteen hours if these optimistic figures are accepted. Considering that the submarine was bottomed for 23 hours, Carbon Dioxide level (partial pressure) should have been quite high. The gradual increases in total pressure within the submarine would have had little effect on this rate of increase or its effect on the survivors, since the effect of the partial pressure increase is independent of the total pressure of Carbon Dioxide increase, unless the gas contributing to the total pressure also was adding extra Carbon Dioxide. Elevated Carbon Dioxide levels has long been thought to increase an individual's susceptibility to decompression sickness but the exact effect is not yet clearly defined.

By the time the crew escaped, Carbon dioxide levels were probably elevated to the point where they would have seriously impaired the ability of the crew to effect escape within a few more hours, and threatened their lives within 24 hours. Pulmonary ventilation is increased by 70% at a carbon dioxide level of 3% (surface equivalent) in the breathing air, and it is increased by a decidedly uncomfortable 150% at a level of 4%. (Most diving rigs are designed to keep the carbon dioxide below 2% at high work loads and most survival techniques in submarines are aimed at levels below 2.5%). The need for the final group to breath alternately from the SCUBA bottle indicates the carbon dioxide had probably exceeded 4% surface equivalent.

MEDICAL RECOMPRESSION TREATMENT

Introduction

All survivors who escaped from PACOCHA while she was still on the surface were taken to the Callao Naval Hospital before midnight on Friday, 26 August. Mobilization of medical personnel and material to support the personnel trapped aboard the submarine began at approximately 0200 on Saturday.

Of the twenty-two crew members who made their escape between 1100 hrs and 1900 hrs on Saturday, twenty were symptomatic for decompression sickness. All twenty-two were treated and diagnosed as having decompression sickness. Although no definite cases of arterial gas embolus occurred, treatment was directed toward arterial gas embolus by utilizing U.S. Navy recompression tables 5A or 6A as initial treatment of at least ten of the survivors.

Once the first escapees arrived at about 1200 on Saturday, medical personnel were busy treating the victims over the next four days. Nine survivors received a second treatment. There was one death during treatment, and another survivor has severe brain damage and quadriplegia. At least one survivor already shows signs and symptoms which herald the onset of dysbaric osteonecrosis, a condition which could ultimately affect all survivors. Several survivors have persisting pain, weakness, changes in affect, and other non-specific symptomatology.

I. Recompression Facilities and Medical Support Equipment

The Peruvian Naval Base at Callao is located on the north side of the city of Lima. It is home for most of the Peruvian Navy including its surface fleet, submarine flotilla, and support facilities. The recompression facility is located in the base's dive locker, approximately three blocks from the submarine flotilla's command center.

The recompression facility normally contains one recompression chamber, a standard U.S. Navy double-lock, 100 psi, 201 cu ft aluminum chamber. The facility has adequate air reserves to pressurize the chamber twice to 165 feet. Subsequent pressurizations rely on the functional capacity of old compressors. Conflicting reports suggested that the outer lock may not have been able to be operated independent of the inner lock.

Oxygen was available, but was only piped to the oxygen manifold in the inner lock. Aviator type masks are available for oxygen treatment in the inner lock.

Fortuitously, at the time of the accident a double lock steel chamber was at the Dive Locker for repair and refurbishment. Upon notification that several individuals might require recompression treatment, repair was begun early Saturday morning and completed by the early afternoon, making the chamber available for treatment an hour or two after the second group of escapees arrived.

A portable chamber, capable of treatment to 165 feet, was obtained from a civilian facility about 800 miles distance from Lima, and sent to the scene on a floating crane. It arrived on station in the late afternoon on 27 August, in time for the fifth group of escapees.

II. Medical Personnel

Seven medical officers provided direct medical support for the recompression treatments. Captain Haro, the Senior Medical Officer and director of the Callao Naval Base Hospital, and Dr. Victor Hugo, Director of the Intensive Care Unit at Centro Medico Naval supervised the initial treatments in the standard U.S. Navy double-lock chamber which, for simplicity, will be referred to as chamber one. Commander Sierralta and Lieutenant Commander Villela supervised treatments in chamber two, the repaired chamber at the Callao Dive Locker, and Lieutenant Commander Murata and Lieutenant Castro were on scene with the portable chamber, chamber three. Commander Ordonez was initially stationed aboard the submarine IQUIQUE near the scene. Later he moved to the Callao Dive Locker to provide assistance.

Four of the six medical officers had training in diving medicine. Captain Haro was trained by the U.S. Navy program at Washington, D.C. in 1972; and he had further training in Argentina in 1984. Commander Ordonez was rained in the U.S. Navy program in 1975. Commander Sierralta and Commander Murata were trained in Argentina in 1987.

Inside tenders were divers with Peruvian Navy nursing training, similar to the U.S. Navy's hospital corpsmen.

All seven of the medical officers and one of the inside tenders were interviewed. Only one of this group, Commander Ordonez, spoke English. Hence, most of the information had to come through an interpreter.

III. Treatment

Twenty individuals developed symptoms and all twenty-two individuals were diagnosed as having decompression sickness, type I or type II.

Symptoms were suspicious for arterial gas embolus in several individuals. Four individuals were diagnosed as having subcutaneous emphysema.

All twenty-two escapees were treated by recompression utilizing U.S. Navy treatment protocols. Because medical personnel expected to see arterial gas embolus, not decompression sickness, treatment tables 5A and 6A were selected as the preferred treatment for many of the survivors. Not until Sunday, upon learning that salvage air had purportedly been used to pressurize the compartment, did medical personnel recognize that the symptoms they witnessed might represent decompression sickness rather than arterial gas embolus.

The first group of survivors reached the Callao Dive Locker approximately 40 minutes after surfacing. They were immediately recompressed to 165 feet on a treatment table 6A. According to LT Gomez and Chief Monzon, both of whom were being treated along with Petty Office Reyes, all three were oriented and free of major symptoms at 165 feet. During ascent, after completing the required thirty minutes at 165 feet, both Chief Monzon and Petty Officer Reyes became comatose and may have had seizures. According to the Medical Officers, they were then returned to 165 feet where they remained for ninety minutes before being brought out on treatment table 4.

Lieutenant Gomez's testimony is at variance with this account, however. He states that in spite of the worsening condition of Chief Monzon and Petty Officer Reyes, they continued to ascend to the surface where he was taken out of the recompression chamber and he thinks another person more serious than himself was put into the chamber before it was pressurized.

On the surface, Lieutenant Gomez states that he developed severe pain which was treated with Demerol. He was also treated with oxygen and intravenous fluids. Ultimately he lost consciousness while waiting to be treated. An official summary, (Appendix 8) shows that Lieutenant Gomez was treated in chamber two on a treatment table 6, and two other individuals, Petty Officer Gomez from the second group of survivors and Chief Michuy from the third group, were treated in chamber one on a Treatment Table 4.

Various accounts placed anywhere from two to five survivors in chamber one during the thirty-eight hour Treatment Table 4. The testimony of Lieutenant Gomez and one official document made available to this assist team are difficult to reconcile with the testimony of the medical officers, especially since the oxygen manifold in the inner and outer locks will only handle three BIBS masks each, and oxygen was only piped to the manifold in the inner lock. If more than two survivors were treated on a Treatment Table 4, the inside tender could not go on oxygen as required during the last four hours.

Chief Monzon testified that he was free of symptoms throughout the initial recompression treatment, conflicting with Lieutenant Gomez's and medical personnel's account that he was comatose during much of the initial treatment table 4. By Chief Monzon's account, symptoms did not occur until two days later, at which time he was treated on an eighteen hour table. Official records show that he was retreated with a Treatment Table 4, probably beginning sometime Sunday evening.

According to medical personnel, the (less critical) survivors in group 2 and apparently, Lieutenant Gomez) waited along with the third and fourth groups until the second chamber was ready at approximately 1800 on 27 August. At this time, it appears that those who were more critically ill were treated with a Treatment Table 6A, followed by the rest who were treated with a Treatment Table 6. The exact course of events is unclear.

The fifth group was treated at the scene in a portable recompression chamber on a floating crane barge. Lieutenant Cotrina noted that his symptoms began within a minute of surfacing. He had pain in both shoulders, then pain all over. His chest and neck felt swollen and he described a crackling sensation when he felt his neck. He was diagnosed medically as having Type 1 decompression sickness and subcutaneous emphysema. Recompression on a Treatment Table 5A occurred within five minutes of reaching the surface. As soon as recompression began, he noted his symptoms disappeared, but when they were surfacing, symptoms reoccurred "....requiring them to take me back down three more times." The official summary available to this team states that he was retreated with a Treatment Table 5 at a later time.

According to all medical testimony, all individuals received intravenous fluids and received 250 mg of Hydrocortisone initially. The more critical patients received Dexamethasone, 8 mg every eight hours. During transport to the recompression facilities, oxygen was not used because adequate portable supplies were not available.

Most medical supplies are in short supply in Peru. Before the treatment period was over, the Navy had to borrow medication and intravenous fluids from civilian medical facilities.

Five of the twenty-two escapees were interviewed. Subjective recollections of the survivors covering the treatment period were variable as to detail as might be expected. Five months had elapsed, and all were suffering from some degree of decompression sickness, with many showing evidence of impaired mental status at the time of the accident. Further, the survivors were submariners, not divers and therefore unfamiliar with recompression procedures, times and tables.

We were unable to reconcile some differences, when certain survivors' recollections were inconsistent both between individuals and some available records. Logs for each treatment documenting who was treated, when the treatment occurred, what treatment table was used, etc., would have been immensely helpful. The official document made available which summarizes to some degree the recompression treatment received by the survivors is included (Appendix 8).

IV. Discussion

Not until Sunday did medical personnel learn that salvage air had been connected to the submarine. Assuming it had been opened, only then did they realize that they might be dealing with decompression sickness in addition to or instead of arterial gas embolus. Although their conclusion was correct, the rationale behind the conclusion was incorrect: External salvage air did not increase the pressure, other factors did, as discussed in a previous section.

Since the survivors were exposed to gradually increasing pressure for nearly twenty-four hours, their tissues were saturated with nitrogen at a depth deep enough to produce decompression symptoms. Even tissues that take up nitrogen very slowly (hence termed "slow tissues"), had accumulated significant amounts of nitrogen. Conversely, while being decompressed these tissues give off nitrogen very slowly. This fact must be considered when planning decompression or treatment of saturated victims of decompression sickness. Such decompression tables and treatment tables should be long, and make optimal use of oxygen to speed off-gassing of nitrogen. Recompression with air to depths deeper than sixty feet, which is the maximum safe depth for use of 100% oxygen, decreases the rate of off-gassing of nitrogen. The survivors who were recompressed to 165 feet were adding nitrogen to their system during the deeper exposures.

A short treatment table which goes to a depth of 165 feet increases nitrogen on-gassing when deep at 165 feet, but does not provide enough time on 100% oxygen at 60 feet to adequately off-gas the slower tissues. When two of the survivors in group four were treated with a Treatment Table 5A, both required retreatment. The U.S. Navy no longer uses Treatment Table 5A and considers it inadequate for the treatment of gas embolism.

Both treatment table 5A and 6A are intended for treatment of arterial gas embolus, not decompression sickness. All survivors had decompression sickness to one degree or another; whether any had arterial gas embolus also is difficult to establish with such a cursory look at patient signs and symptoms. Certainly everyone would have expected some of the survivors to have arterial gas embolus, considering the minimal training, the anxiety, and the fact that they made buoyant ascents without their hoods on. Rather than breathing normally, they had to breathe out all the way to the surface. Amazingly, the two known non-swimmers who escaped with Lieutenant Cotrina did not show signs of arterial gas embolus. Of the entire group, Petty Officer Grande, the only fatality during recompression, was most likely to have had an arterial gas embolus.

Had medical personnel been thinking "decompression sickness" rather than "arterial gas embolus", treatment depth to 60 feet with immediate oxygen breathing might have been more effective. By eliminating the secondary on-gassing of nitrogen which occurs during treatment on air at 165 feet, the worsening of decompression sickness associated with upward travel might have been minimized. Also, critically ill patients would not have gotten "stuck" at a depth which precludes use of 100% oxygen, and makes provision for medical care extremely difficult. One inside tender did develop decompression sickness and was still hospitalized and undergoing rehabilitation therapy for residual symptoms.

Individuals who have been exposed to compressed air for periods that approach saturation times will more than likely require longer periods of decompression for adequate off-gassing of nitrogen from their tissues than a Treatment Table 6 will provide. At sixty feet critically ill patients could have made direct lateral shift to a U.S. Navy Treatment Table 7 (Saturation Treatment Table). While the chamber is held at 60 feet for a minimum of 12 hours as Table 7 requires, critically ill individuals arriving at the recompression facility at any time could be compressed to 60 feet, hopefully via an operable outer lock until the ventilation and habitability limits of the chamber are reached. If the outer lock were, in fact, not operable, brief surfacing from 60 feet with the occupants on oxygen, would have been much less dangerous than surfacing from deeper depths with the occupants on air. Such surfacings certainly are not recommended however.

When logistics make use of a Treatment Table 7 impossible, (i.e., Staff shortages, inadequate air for ventilation purposes, inadequate oxygen supply, inability to effectively remove carbon dioxide, inability to keep the chamber cool), then treatment of saturated individuals with decompression sickness on Treatment Table 6 will probably prove inadequate with recurrence or exacerbation of symptoms likely when attempting to follow the table. Obviously this occurred since several patients were retreated.

Ideally, patients with residual symptoms after the initial treatment should have multiple retreatments on a daily basis. Unfortunately, however, the patient in greatest need of ongoing, daily treatments, Petty officer Reyes, did not receive any; and Chief Mozon, who had a neurogenic bladder, was retreated with a table four. Current hyperbaric medical philosophy requires that, at the time of retreatment, a patient needs oxygen at high pressure, not high pressure air as table four provides. Any but the most sophisticated recompression facilities would have been overwhelmed by the sheer number of casualties. Considering the trained people, equipment, and supplies available, those involved did an outstanding and heroi ob. Second guessing treatment decisions is unfair, especiall considering the number of lives saved by the actions of all . olved in the treatment of the survivors. Without the efforts extended, many more would be dead or crippled for life. This retrospective analysis is included as lessons learned to enhance future planning.

LESSONS LEARNED

In dealing with submarine escape and rescue, pressurization of a disabled submarine is easily unrecognized, unanticipated, overlooked or underemphasized. As a result, rescuers may be ill-prepared to deal with the results and even risk compounding the problems. The PACOCHA is a perfect example. A combination of common sense, use of the best information available, dedication, maximum utilization of available assets, some luck, and superb leadership by individuals such as Admiral Tirado and LT Cotrina minimized the effects of this unexpected encounter with pressurized submarine escape. The generosity of the Peruvian Navy in sharing lessons learned, so that all submariners might benefit, required courage as well as dedication to the ancient traditions of men who follow the sea helping one another. It is easy to second guess or criticize those who participate in any unplanned disaster reaction. This document is written with admiration for those who met the challenges and with hope that any who read it will use the information for constructive purposes only.

1. Communications with rescue teams from the United States should continue until the emergency is over, even when the actual rescue system may no longer be required. The expertise of the team members, particularly the Undersea Medical Officers, as well as certain equipment such as portable hyperbaric chambers can be invaluable.

2. All embassies should have complete information on any support agreements formulated for emergency support between the United States Navy and another country's Navy. This should include primary contact points and telephone numbers. Ideally, such information should include the availability of local support equipment such as cranes, compressors, hyperbaric chambers, and support craft.

3. Submarines transiting on the surface with open hatches prior to entering the actual sheltered waters of the berthing area are at increased risk of flooding when emergencies develop.

4. All individuals who go above decks should be equipped with emergency flotation devices at all times.

5. Steinke hoods and life vests do not give adequate protection from thermal stress in cold water.

6. Collision Alarms should be sounded early enough to enable those below decks to ensure the water tight integrity of all compartments when a collision is possible.

7. Main Induction as well as all other penetrations should be

closed immediately when a submarine begins to sink.

8. Compression of survivors in a disabled submarine to pressures requiring special rescue and escape techniques does occur in real accident scenarios.

9. Gauges or monometers with a range of 0-10 atmospheres should be available in all compartments to measure pressurization within the compartment. Logs should be kept of such changes, particularly in an emergency situation.

10. Rescue and/or escape should not take place until the internal pressure of the submarine and the depth of the water are taken into account. This information will enable those on the surface to avoid, or at least anticipate, the risk of decompression sickness and make the best possible preparations for handling casualties.

11. All boat compartments and potential surface rescue support groups should have guidelines for rescue and escape procedures, including options from a pressurized compartment. Options for escape and some rescue techniques may become increasingly hazardous as time passes.

12. Decompression of survivors within a disabled submarine prior to escape or rescue may be necessary. This can be due to the lack of a pressurized rescue system, a shortage of sufficient hyperbaric chambers on the surface, or excessive pressurization that prevents safe escape. Armored salvage hoses, proper connectors, controllable valves and pressure gauges as well as a sufficient source of clean air would then be mandatory.

13. Flying escapees from a pressurized submarine by helicopter requires the pilots to fly at minimum altitude to prevent exacerbation of decompression sickness.

14. Maintenance of an acceptable atmosphere in a disabled submarine is extremely difficult when no monitoring equipment is available. In such a situation, Carbon Dioxide adsorbents should be spread out to the maximum extent possible and as soon as possible in the surviving compartments of a disabled submarine. Guidelines available for submariners should be reviewed and updated.

15. Battle lanterns should be evenly distributed in all compartments sufficient to give emergency lighting for 48 hours.

16. Carbon Dioxide fire extinguishers are not necessarily the best choice for use aboard submarines in a closed environment when surface ventilation is impossible.

17. Salvage and rescue teams as well as submarines should have a

standard set of tap communication signals for diver/survivor communications. These should be available in all submarine compartments as well as at all diving commands.

18. In a relatively shallow sinking, divers can supply a surviving compartment with life support supplies and monitoring equipment as well as lights, food, water, and clothing. The DSRV or McCann chamber can also carry out this mission. Prolonged survival and decompression in the compartment can then be more feasible than would be possible with only the submarines initial surviving assets.

19. Steinke hood escape training and techniques should be carefully taught and periodically reviewed. Use of the escape device without the hood increases the risk to survivors. Maintenance and inspection of the hoods should be a required on a regular basis.

20. Escape training should include training on the operation of hatches and valves, so that the escape trunk can be operated repeatedly for successive groups of escapees. Routine maintenance of remote hatch operating controls is also critical in all escape trunks.

21. Once the decision to escape is made, based on deteriorating conditions, all groups should do so quickly before conditions, such as rising Carbon Dioxide levels, increase the hazards of escape even further. The order of escape should be established before each group enters the escape trunk. Time at pressure in the trunk must be minimized.

22. Ships of opportunity frequently will be unable to deliver compressed air of breathing quality in large quantities. A portable air filter that can be taken to the accident site and utilized would be useful.

23. The most current diving manuals, decompression tables, and guidelines for the use of pressure and oxygen in treatment should be made available to all rescue teams in counties with whom the United States has a submarine rescue or diving support agreement.

24. Hyperbaric chamber tenders require oxygen during the final phases of certain recompression treatment tables. Oxygen masks must be available for them, as well as the patients, to avoid additional cases of decompression sickness among the tenders.

25. Repeated daily chamber treatments with hyperbaric oxygen are indicated when a patient does not fully recover during initial recompression therapy.

26. Cranes intended for lifting heavy objects, such as the Submarine Rescue Chamber, particularly in an emergency should have periodic inspections and recertification.

27. Guidelines for use of the Submarine Rescue Chamber, (SRC), in pressurized rescue scenarios should be reviewed. The SRC can make recoveries at depths down to 850 feet. It can be internally pressurized to a pressure of 290 feet (128.7 PSIG) as long as the internal pressure is no greater than 15 PSIG above external pressure. This mode of recovery would require decompression on the way to the surface and thus use up all of, or at least a great deal of, any allowable surface interval before transfer of the rescuees to a recompression chamber on the surface even begins.

28. The design of the high and low salvage connections make it difficult for divers and impossible for submersibles to complete connections of salvage hoses.

29. Decompression sickness following pressurized escape or rescue can include both acute and delayed symptoms, including Dysbaric Osteonecrosis appearing months later. Victims of such accidents should be followed medically for a prolonged period of at least one year.

30. Deck workers should wear survival suits on submarines operating in cold waters.

RECOMMENDATIONS

1. Supply every escape compartment on a submarine with atmosphere monitoring equipment for oxygen, carbon monoxide, and carbon dioxide and a gauge by which compartment pressure can be monitored.

2. Survivors in a disabled submarine should maintain an ongoing log of the atmospheric pressure in the submarine.

3. Insure that submarine crew members initial training covers the physiologic significance of elevated atmospheric pressure in a compartment and during escape and rescue.

4. Every escape compartment and rescue team should have tables showing how long a person can stay under pressure t a given depth without incurring decompression obligation ("No decompression" tables - Appendix 6). In addition, they should have a table showing the internal pressure limits that permit escape from various water depths without encountering significant risks of decompression sickness (Appendix 7).

5. Survivors in a disabled submarine should convey pressure data to the surface, and this data should be relayed to medical personnel trained in diving medicine. If this information is not conveyed, those on the surface should ask for it. Rescue teams should have decompression tables and guidelines for pressurized rescue and decompression.

6. For purposes of providing a life sustaining atmosphere, armored (Pressure resistent) salvage hoses should be made available to salvage tams for connection with the high and low salvage connections of all submarines in service. Connectors should be available to connect with the salvage fittings as well as to supply high pressure air to either of these hoses. The hoses should have sufficient length or sections to reach all submarines in service at their crush depth. The hoses also require the strength to deliver high pressure air at these depths as well as the tensile strength (or a mated cable) to reach such depths.

7. Consideration should be given to modifying all high and low salvage fittings to allow easy connection of salvage hoses by divers or small submersibles. The current connector system is difficult even for a diver and impossible for a submersible. Such salvage fittings should be established internationally and standardized internationally.

8. A salvage air system should be developed with a valve at the surface ends of both lines so pressure in the submarine can be controlled. Gauges to read the pressure in both high and low

salvage lines must be present. The salvage air system should ideally provide the option of controlled pressurization and decompression.

9. The low salvage line in a submarine compartment should be modified to allow ventilation of the submarine without blowing water from the bilges. A flexible armored hose or pipe could be available for attachment to the underwater end of the low salvage line to enable air to enter the line rather than water. Another option would be to install a "ventilation" valve in the low salvage line, higher up within each compartment and to be opened only for ventilation purposes.

10. Salvage air intended for ventilation purposes in a submarine should have an inline filter system to remove contaminants. Salvage and rescue teams should be supplied with a portable filter to use with sources of high pressure air on vessels of opportunity.

11. Train submariners as well as salvage and rescue teams to make decisions, in conjunction with diving medical officers, as to when and how to decompress the survivors.

12. A three day supply of Lithium Hydroxide canisters should be carried on board. This represents 8.7 pounds of Lithium Hydroxide per man. For a crew of 50, this would be 435 pounds or approximately 70 canisters. PACOCHA had approximately 28 canisters available in the forward compartments. Presumably, more were inaccessible in the flooded aft compartments. Guidelines for their use should be reevaluated.

13. Instruct submariners that larger quantities of Lithium Hydroxide should be used than were used on PACOCHA. Some experts advocate putting out s much as possible immediately to slow the initial rise in Carbon Dioxide and allow maximal physiological adaptation among the survivors to the rising level of Carbon Dioxide as it occurs.

14. If the Lithium Hydroxide is spread on bunks, it should be spread on lower bunks if possible. Polyethylene film could be spread under it to keep it from getting wet if the bunks are wet. Maximum circulation of air across the absorbent bed and within the compartment should be maintained even by manual means.

15. The British have investigated a manual powered blower which effectively circulates air through canisters of Carbon Dioxide absorbent. It should be technically evaluated, particularly under conditions at elevated pressure, and considered for retrofit aboard active submarines.

16. Guidelines for operation of the McCann Bell when rescuing personnel from a pressurized submarine should be reviewed,

updated, and distributed.

17. Ensure that all Naval Submarine and Rescue Commands as well as military attachees have copies of escape and rescue agreements as well as pertinent points of contacts listed, easily accessible and up to date.

18. Establish improved storage and periodic testing of [illegible] of Lithium Hydroxide. Storage of the containers in plas[illegible] might help prevent rusting of the containers.

19. Periodic testing of the air banks and air compressors for contaminants in the compressed air would establish the breathing quality of the stored gas. This would improve emergency response capabilities although it would increase maintenance costs and support requirements.

20. We recommend a complete radiographic evaluation of all 21 surviving escapees for dysbaric osteonecrosis at some time between 6 months and 1 year following the accident.

21. A published medical review by Peruvian Medical Personnel of each person who escaped from the PACOCHA including exact experiences during the accident, entrapment, escape, treatment and long term recovery phases would be valuable to the international medical community.

22. Review the Steinke Hood maintenance and training programs. The escapees elected not to use the hood portions and this increased their risk of gas embolism and drowning as well as thermal stress.

23. Increase the number of serviceable battle lanterns within compartments of each submarine.

24. Create a small library in Peru of Undersea Medical Textbooks and subscribe to at least the three most critical journals in the field: Undersea Biomedical Research; Journal of Hyperbaric Medicine; Aviation, Space and Environmental Medicine. This small library should be available to both the Doctors trained in Undersea Medicine and the interested Nurses, as well as Submariners and Divers. Include an up to date copy of the U.S. Navy Diving Manual.

25. Petty officer REYES has severe brain and spinal cord damage secondary to decompression sickness. This team reviewed his stat[illegible] with the physicians responsible for the care and saw Petty Offi[illegible]. Reyes at the hospital. This type of decompression in[illegible] is not reversible after this ammount of time by any treatment known to modern medicine or recompression therapy. There is nothing to be gained by subjecting the patient to an arduous trip to the United States or elsewhere for consultation

or treatment. He needs supportive care and physical therapy to maximize any small gains he may make.

26. Recompression of large numbers of patients simultaneously is impossible in the old. small chamber currently at Callao. Modern hypertbric oxygen therapy is also impossible to deliver to seriously ill patients requiring sohisticated medical attention. Long term planning and acquisition for a large, sophisticated hyperbaric chamber to support the Navy, the Hospital and the oil diving industry in that area of the world would be a major asset. This chamber should be capable of supporting saturation recompression therapy such as U.S. Navy Treatment Table 7.

27. The current recompression chamber at Callao should be updated and capable of supporting, with oxygen, 3 people in the inner lock and two in the outer lock. Additional chambers, their locations, capabilities and readiness status should be available to Admiral Tirado's office.

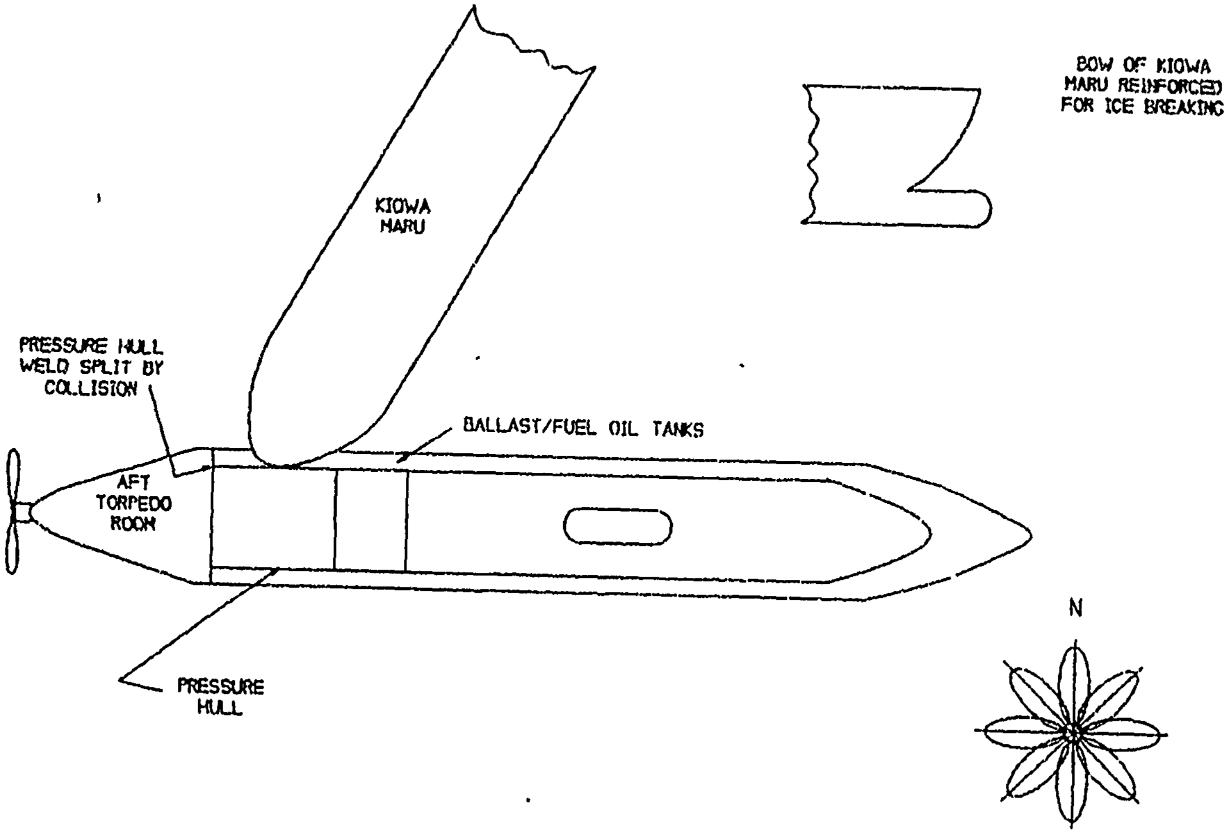
28. Communication and support from U.S. medical and rescue personnel should continue even if a requirement for the actual rescue vehicles (DSRV, McCann chamber) is absent or aborted. Other support such as fly-away recompression chambers, technical expertise or other equipment may prove valuable.

29. The types of fire extinguishers caried for use during fires in compartments on disabled submarines needs review and guidance, particularly in relation to carbon dioxide extinguisher use.

30. Consideration should be given to adopting the British Submarine Escape and Immersion Survival Suits (SEISS) for use in isolated or wartime situations. Major modifications of escape trunks would be neccessary to adapt existing submarines to exploit the full 200 meters escape potential of the suit. However its potential for incrasing survival potential in cold water could be realized with only minor escape trunk modifications in existing submarines.

31. Consider development or procurement of an improved immersion survival suit for personnel who might go overboard at night. Such a suit should keep a man alive for 9-12 hours in cold water.

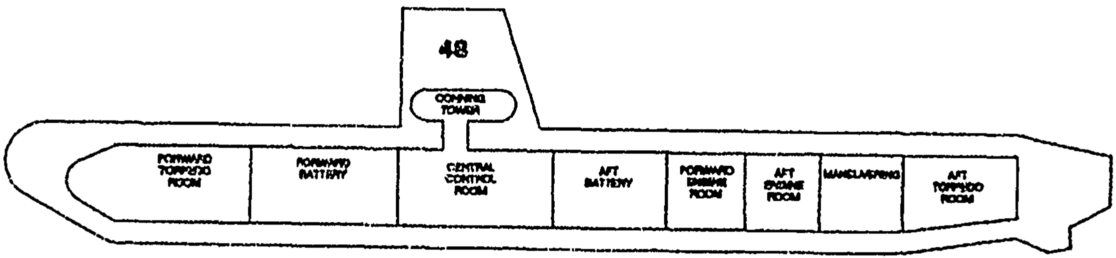
32. A visit by a U.S. military training team to familiarize naval personnel of other countries with U.S. submarine rescue techniques, would assist planning, communications, and contingency reactions in the future.



BOW OF KIOWA
MARU REINFORCED
FOR ICE BREAKING
KIOWA
MARU
PRESSURE HULL
WELD SPLIT BY
COLLISION
BALLAST/FUEL OIL TANKS
AFT
TORPEDO
ROOM
PRESSURE
HULL
N

Appendix 1.

Appendix 2.



B.A.P "PACOCHA" (SS-48)

LIST OF PERSONNEL WHO ESCAPED FROM B.A.P. "PACOCHA" ON 27 AUG 1988

PRIMER GRUPO

1. Tto.1. Franz GOMEZ Collazos
2. T3.Eco. (SS) Lufa MONZON Millones
3. OM2.Mot.(SS) Alberto REYES Vilca

SECUNDO GRUPO

4. Tte.2. Agusto ARANGUREN Nieri
5. OM1.Ele.(SS) Pascual GOMEZ Pena
6. OM1.Ele.(SS) Alberto GOMEZ Contreras
7. OM3.Mot.(SS) Nicolas TELLO Cacha

TERCER GRUPO

8. T3.Ele. (SS) Virgilio MICHUY Suyo
9. OM1.Ele.(SS) Jorge TOLENTINO Ayllon
10. OM1.Coc.(SS) Celso NIEVES Chero
11. OM2.May.(SS) Carlos MARTINEZ Dieguez
12. OM2.Son.(SS) Freddy MURGA Rivas

CUARTO GRUPO

13. OML.Ele.(SS) Aurelio AGAPITO Roca
14. OM1.Ele.(SS) David ARGUME Pomalaya
15. OM1.Rad.(SS) Hilton SANDOVAL Palacios
16. OM2.Coc.(SS) Ricardo VINCENTE Jimenez

QUINTO GRUPO

17. Tte.1. Roger COTRINA Alvarado
18. T3. Mot.(SS) Juan ANGULO Garcia
19. OM1.Ele.(SS) Jose CONTRERAS Espiritu

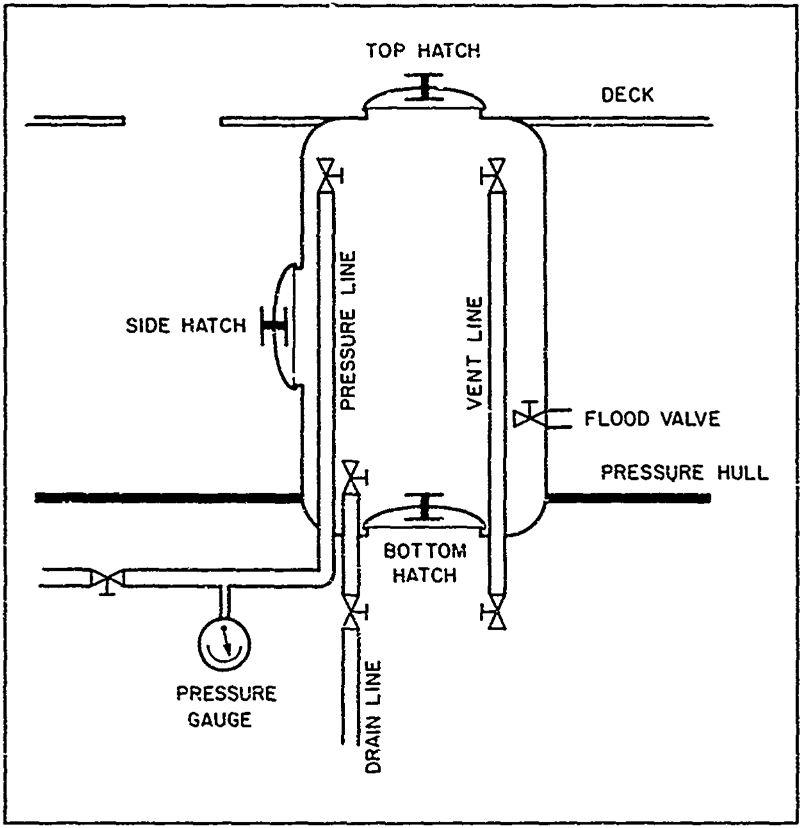
SEXTO GRUPO

20. Tte.2. Cristian LINDLEY Ruiz
21. T3. Ars.(SS) Aurelio BENDEZU Sanchez
22. Om2.Rad.(SS) Carlos GRANDE Rongifo (Fallecido 28-08-88)

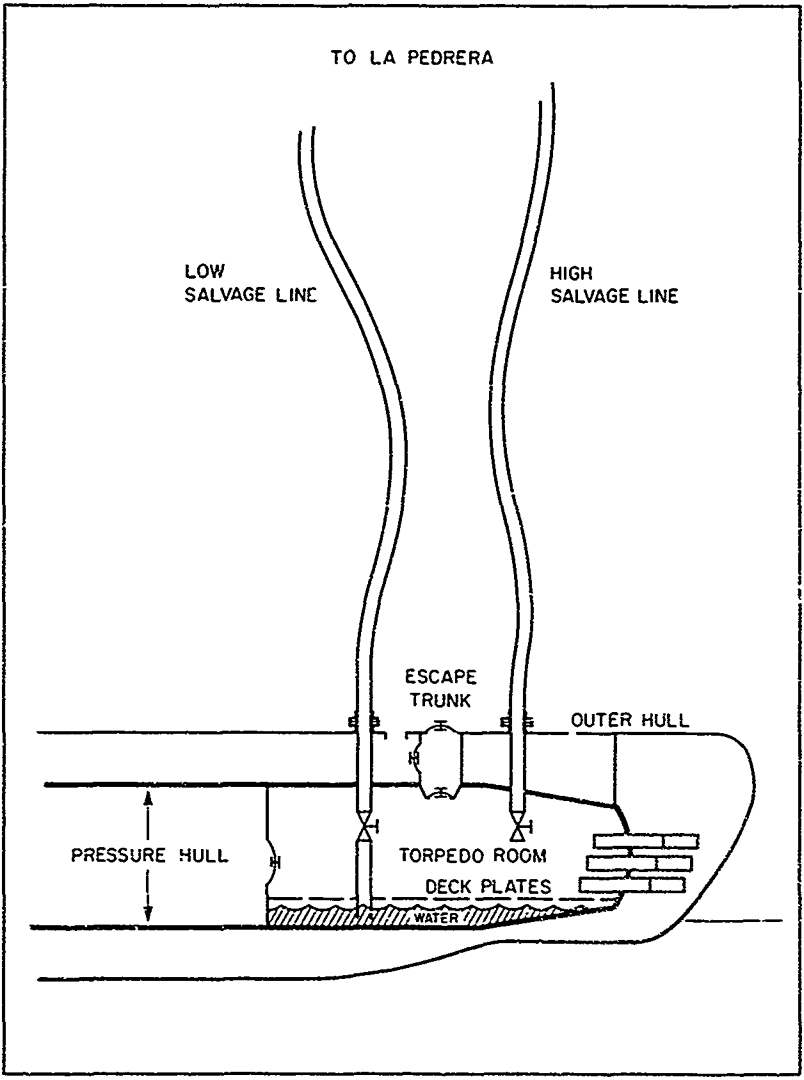
PERSONNEL LISTED AS DISAPPEARED PROBABLY TRAPPED IN THE INTERIOR OF THE SUBMARINE

1. TTE.2. Luis ROCA Sara
2. T3. Sen.(SS) Rigoberto GONZALES Pisfil
3. OM1.Mot.(SS) Juan ORE Rojas

NOTE: The Commanding Officer was trapped in the sail, found at a later date.



FORWARD ESCAPE HATCH OF PACOCHA (HIGHLY DIAGRAMATIC AND SIMPLIFIED) SHOWING PRESSURE GAUGE ON LINE SUPPLYING AIR PRESSURE TO ESCAPE TRUNK.

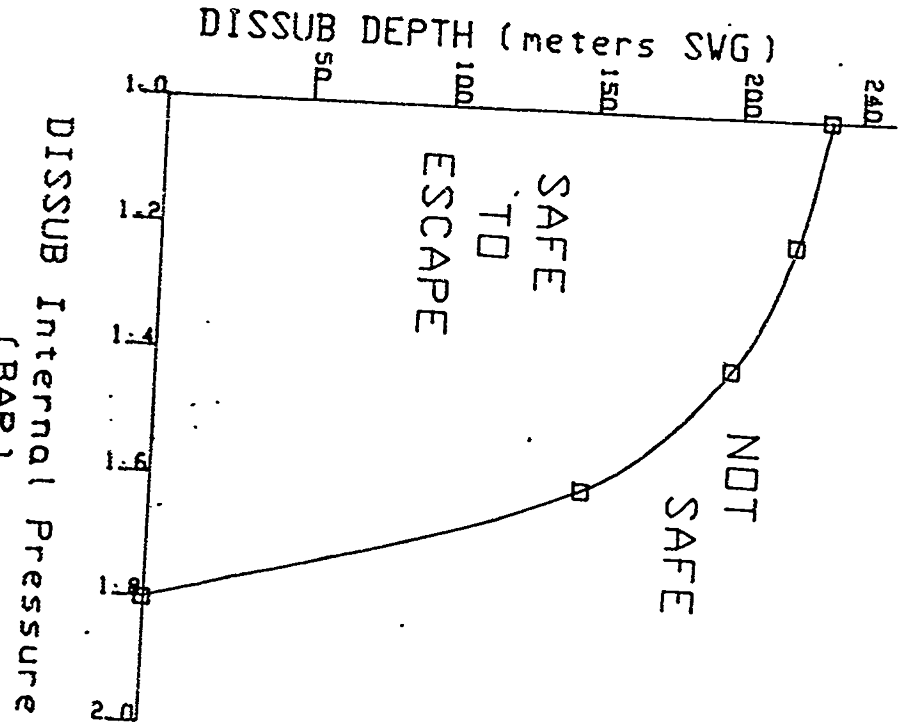


HIGH AND LOW SALVAGE CONNECTIONS FOR A SUBMARINE (DIAGRAMATIC)

NO DECOMPRESSION LIMITS FOR AIR

DEPTH (feet)	No-decompression limits (min)
<35	UNKNOWN
35	310
40	200
50	100
60	60
70	50
80	40
90	30
100	25
110	20
120	15
130	10
140	10
150	5
160	5
170	5
180	5
190	5

SUBMARINE ESCAPE DEPTH LIMITS



LIST OF PATIENTS, DIAGNOSES AND TREATMENT OF PERSONNEL FROM B.A.P. "PACOCHA"

PRIMER GRUPO

1. First Lieutenant Frank GOMEZ Collazos
   Dx: DCS II Bends (Pain) Left hip, both knees
   Rx: TT6 + 6 Chamber 2

2. Third Lieutenant Luis MONZON Millones
   Dx: DCS II (Sx ________) ETA (? = gas embolism ?)
   Neurogenic bladder
   Rx: 4 + 4 (SERSAL) Chamber 1

3. OM2 (PO2) Alberto REYES Vilca
   Dx: DCS II (Sx ___________) ETA (gas embolism ?)
   somnolence, L hemiparesis, babinski on L
   Rx: TT4 Chamber 1

SECUNDO GRUPO

4. First Lieutenant Augusto ARANGUREN Nieri
   Dx: DCS II Bends (ARE (?) Nausea
   Rx: TT6A Chamber 2

5. OM1 (PO1) Pascual GOMEZ Pena
   Dx: DCS II Bends (pain) (RI (? = L knee, both shoulders
   Rx: 6 (SERSAL) Chamber 2

6. OM1 (PO1) Alberto GOMEZ Contreras
   Dx: DCS II Bends (Pain) shoulders, myalgia of arm, paraparesis of distal lower members
   Rx: TT4 Chamber 1

7. OM3 (PO3) Nicolas TELLO Cacha
   Dx: DCS II Bends (Pain) (HI ED ?) = (? rand L shoulder?), headache
   Rx: TT6 + 6 Chamber 2

TERCER GRUPO

8. T3 Virgilio AICHUY Suyo
   Dx: DCS II Bends (Pain) (Wrists, elbows, knees, ankles)
   Rx: TT4 Chamber 1

9. OM1 (PO1) Jorge TOLENTINO Ayllon
   Dx: OCS II (Sx ___________)
   Rx: TT6A (SERSAL) Chamber 2 TT6 Cervical pain myalgia (back) SERSAL Chamber 1

10. OM1 (PO1) Celso NIEVES Chero
    Dx: DCS I (Sx _______)
    Rx: TT6 (Location _________)

11. OM1 (PO2) Carlos MARTINES Diaguez
Dx: DCS II Bends (pain) Knees, ankles
Rx: 6A (SERSAL) Chamber 1

12. OM2 (PO2) Freddy MURGA Rivas
Dx: DCS I Bends (Pain) R wrist, myalgia (MII) (? = L. leg)
Rx: TT6 Chamber 2

CUARTO GRUPO

13. OM1 (PO1) Aurelio ROCA Agapito
Dx: DCS II Bends (Pain) Shoulders and knees
Rx: TT6 Chamber 2

14. OM1 (PO1) David ARGUME Pomalaya
Dx: DCS II (Sx __________)
RX: 6 + 6 Chamber 3

15. OM1 (PO1) Hilton SANDOVAL Palacios
Dx: DCS II Bends (pain) Knees, L Bracheal monoparesis and SQ emphysema (Location: _____)
Rx: TT6A (SERSAL) Chamber 1

16. OM2 (PO2) Ricardo VICENTE Jimenez
Dx: DCS II (Sx ___________)
Rx: TT6 Chamber 2

QUINTO GRUPO

17. First Lieutenant Roger COTRINA Alvarado
Dx: DCS I Bends (Pain) L. Shoulder
Gas intoxication SQ emphysema (Location:)
Rx: TT5A + 5 Chamber 3

18. Third Lieutenant Juan ANGULO Garcia
Dx: DCS II Bends (Pain) HD (? = R shoulder), dorsal pain (?)
Rx: TT5A Chamber 3 TT6 Chamber 1

19. OM1 (PO1) Jose CONTRERAS Espiritu
Dx: DCS II Bends (Pain) Knees, abdominal pain, vomiting
Rx: TT6A (SERSAL) TT4 (pain R Knee, shoulders, chest myalgias) Chamber 1

SEXTO GRUPO

20. Second Lieutenant Christian LINDLEY Ruiz
Dx: DCS Bends (Pain) both knees
Rx: TT6A Chamber 2

21. Third Lieutenant Aurelio BENDEZU Sanchez
Dx: DCS II Bends (Pain) RD (? = Right knee) myalgias R leg IRA (?) and SQ emphysema (location: ___________)
Rx: TT6A Chamber 1

22. OM2 (PO2) Carlos GRANDES Rongifo
Dx: DCS II (Severe Sensory Defect, shock, (CID)=(DIC?) = disseminated intravascular coagulation
Rx: TT6A Chamber 2 Died at 1330

NAMES AND TITLES

Rear Admiral Guillermo Tirado Villena, Comandancia Fuerza Submarinos, Base Naval Callao, Callao, Peru

Rear Admiral Herbert Del Alamo Gijaba, Surgeon General, Ministerio de Marina

Rear Admiral Tobias Zuniga Rodriguez, Director Centro Medico

Naval Captain Jose Haro Araujo, Director of the Naval Base Hospital and Qualified in Submarine Medicine. Training in U.S.A. in 1972 and in Argentina in 1984. Medical Officer in charge of rescue team

Captain John Shillingsburg, USN, U.S. Defense Attache, Lima, Peru

Commander Nieva, Commanding Officer, B.A.P. PACOCHA (SS-48)

Commander Richard L. Buck, MC, USN, Officer in Charge, Naval Medical Research Institute, Detachment Lima, Peru

Commander Cesar Ordonez Ortiz, Qualified in submarine medicine, trained in U.S.A. in 1975. ENT specialist. Member of rescue team aboard B.A.P. IQUIQUE

Commander Fernando Sierralta Gutierrez, Medical Officer. Trained in submarine medicine in Argentina in 1987. Neurosurgeon. Member of rescue team

Commander Jose Mitterhofer Passana, Commanding Officer, B.A.P. La PEDRERA (SS-49)

Commander Galarza, neurologist at Centro Medico Naval

Lieutenant Commander Guillermo "Willie" Alexander Smith, Medical Officer, Interpreter for interviews

Lieutenant Commander Vilela, Medical Officer, member of rescue team

Lieutenant Commander Murata, Resident of traumatology, trained in diving medicine, member of rescue team

Lieutenant Commander Jorge Ruiz Silva, diver

Lieutenant Vondell Allred, MSC, USN, Assistant Officer in Charge, Naval Medical Research Institute, Detachment Lima, Peru

Lieutenant T. Gary Pazzaglia, MSC, USN, epidemiologist, Naval Medical Research Institute, Detachment Lima, Peru

Lieutenant Castro, Medical Officer, member of rescue team

First Lieutenant Luis Calmet Mujica, diver

First Lieutenant Walter Granda Esponjol, diver, instructor at the Callao diving school. Trained in Panama City in 1987

Dr. Victor Hugo Rodriguez, internist, in charge of the intensive care unit at Centro Medico Naval

Dr. Guillermo Phillips, neurologist for Petty Officer Reyes at Centro Medico Naval

Dr. Irving Phillips, virologist, Naval Medical Research Institute, Detachment Lima, Peru

OM1(BU) Guillermo Torres Sanca, inside tender, subsequently treated for decompression sickness

UNITS OF INTEREST DURING THE ASSIST VISIT

B.A.P. PACOCHA (SS-48), previously U.S.S. ATULE (SS-403)

B.A.P. LA PEDRERA (SS-49), previously U.S.S. SEA POACHER (SS-406), sister ship of PACOCHA

B.A.P. DOS DE MAYO initial sub sent to search

B.A.P. ABTAO, connected to supply salvage air to PACOCHA

KIOWA MARU, 412 ton Japanese fishing trawler

B.A.P. IQUIQUE, Peruvian submarine standing by to furnish compressed air during escape effort

Unclassified
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C. A. Harvey and J. Carson

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19 ABSTRACT (Continue on reverse if necessary and identify by block number)

At the invitation of the Peruvian Navy, a U.S. Navy team reviewed the circumstances surrounding the collision, sinking, and subsequent escape and rescue of members of the crew of the B.A.P. PACOCHA. Approximately half were rescued after immediate escape before the sinking, with a 2-4 hour cold-water exposure, and the other half were trapped for over 20 hours in the forward torpedo room. They escaped by buoyant ascent, after having been subjected to pressure from partial flooding and air being introduced from the air banks. Escapees suffered decompression sickness and gas emboli after surfacing. The medical response, rescue, evacuation, and recompression treatment of survivors using all available equipment and personnel is reviewed. Some observations are presented that might diminish morbidity and mrotality in the future.

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18. (cont) Dysbaric osteonecrosis; Asceptic bone necrosis; Buoyant ascent

SUPPLEMENTARY

INFORMATION

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OFFICE OF THE CHIEF OF NAVAL OPERATIONS
WASHINGTON DC 20350 2000

ERRATA

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To: Director, Defense Technical Information Center

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1. The need for a limited distribution statement for reference (a) is no longer required. The Peruvian government approved the release of the report to any requesting foreign government on an unrestricted basis on 4 December 1989.

D. O. GRIFFITH
By direction

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