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ANALYSIS OF ARRAY COMPONENTS RECOVERED AT ST. CROIX, VI,(U)
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ANALYSIS OF ARRAY COMPONENTS RECOVERED AT ST. CROIX, VI

Research & Engineering Department

May 1977

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Keyport, Washington 98345

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NAVTORPSTA Report 1332, *Analysis of Array Components Recovered at St. Croix, VI*

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The pressure housings with electronic instrumentation from arrays recovered at the Atlantic Fleet Weapons Test Facility (AFWTF) in St. Croix, Virgin Islands were disassembled and inspected. A description of the arrays is given and photographs of the parts inspection are shown. Failures and their causes are described and discussed.

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1. INTRODUCTION

BACKGROUND

The Naval Torpedo Station has been analyzing recovered 3-D tracking arrays as part of a continuing program to determine the effects of long-term submergence on underwater equipment used on its ranges. The basic construction of arrays and sealing methods for pressure housings at St. Croix and NAVTORPSTA are similar since they have a common origin at the Applied Physics Laboratory of the University of Washington (APL/UW). However, the arrays at St. Croix appear to have longer service life. The recovery of arrays at St. Croix offered an opportunity to study the effects of the waters there. No direct comparison of the corrosion and its effects was made between NAVTORPSTA and St. Croix arrays. This may be discussed in a future report.

DESCRIPTION OF ARRAYS

The electronics packages from two types of arrays were received for analysis. One set was from array 7, a rigid type as shown in Figure 1; and the other from array 10, a buoyant type as shown in Figure 2. The primary difference in the electronics is that the buoyant type array has a level or tilt sensing device which transmits array tilt information to the shore. The tracking electronics are essentially the same: the hydrophone signals are multiplexed at each individual preamplifier, then combined at the junction box and sent up the cable to the computer site.

ST. CROIX RANGE WATERS

The waters at St. Croix have a relatively high oxygen content, 4 ml/liter, indicating a high corrosion rate. However, the waters at St. Croix are alkaline and the bottom sediment contains a large amount of calcium. This condition accelerates corrosion of zinc but is less corrosive to steel than normal seawater. In the balance, steel corrodes at a lower rate at St. Croix than in Pacific waters. Table 1 below shows water conditions at three tracking ranges.

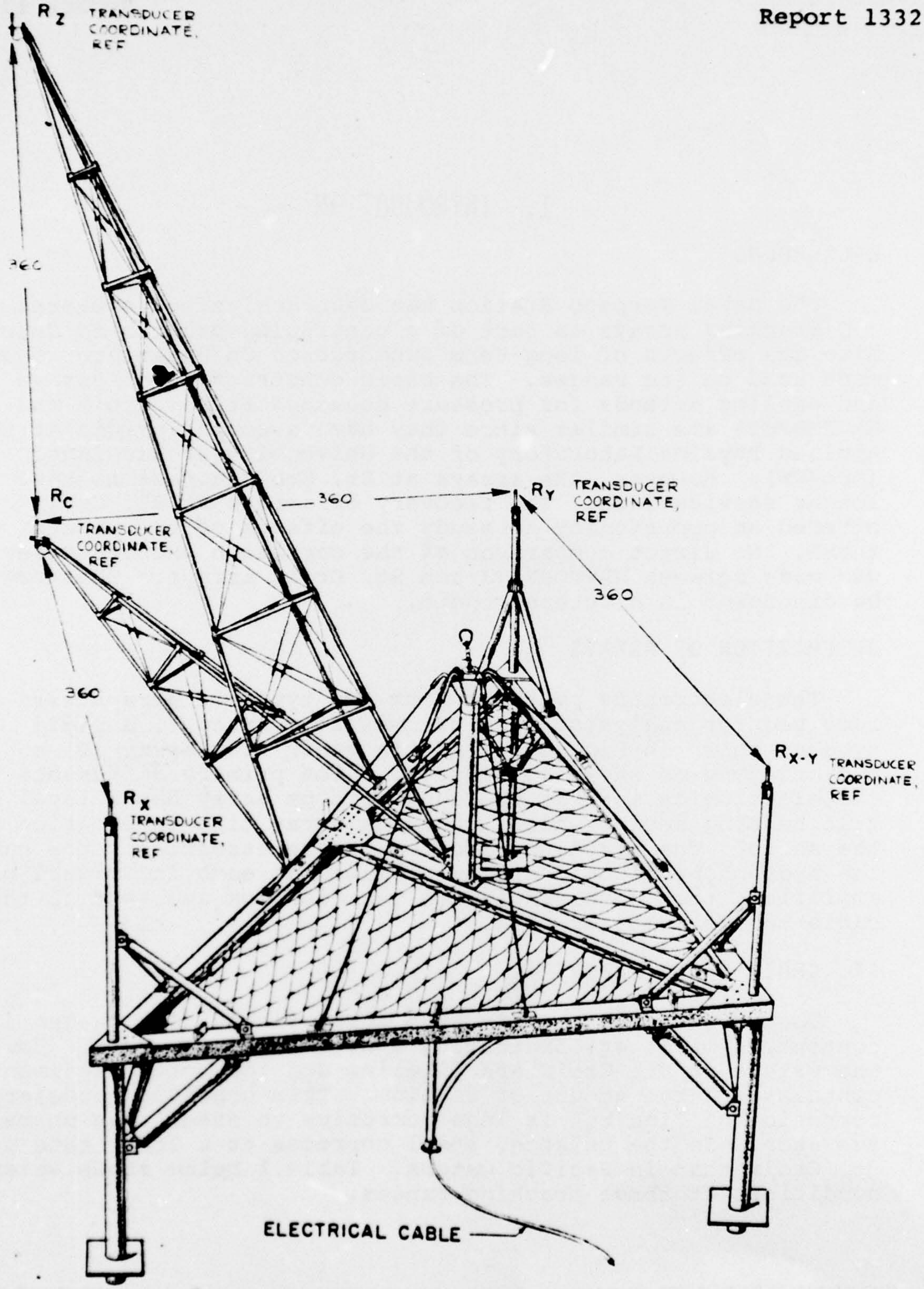

Figure 1. Rigid Array, St. Croix

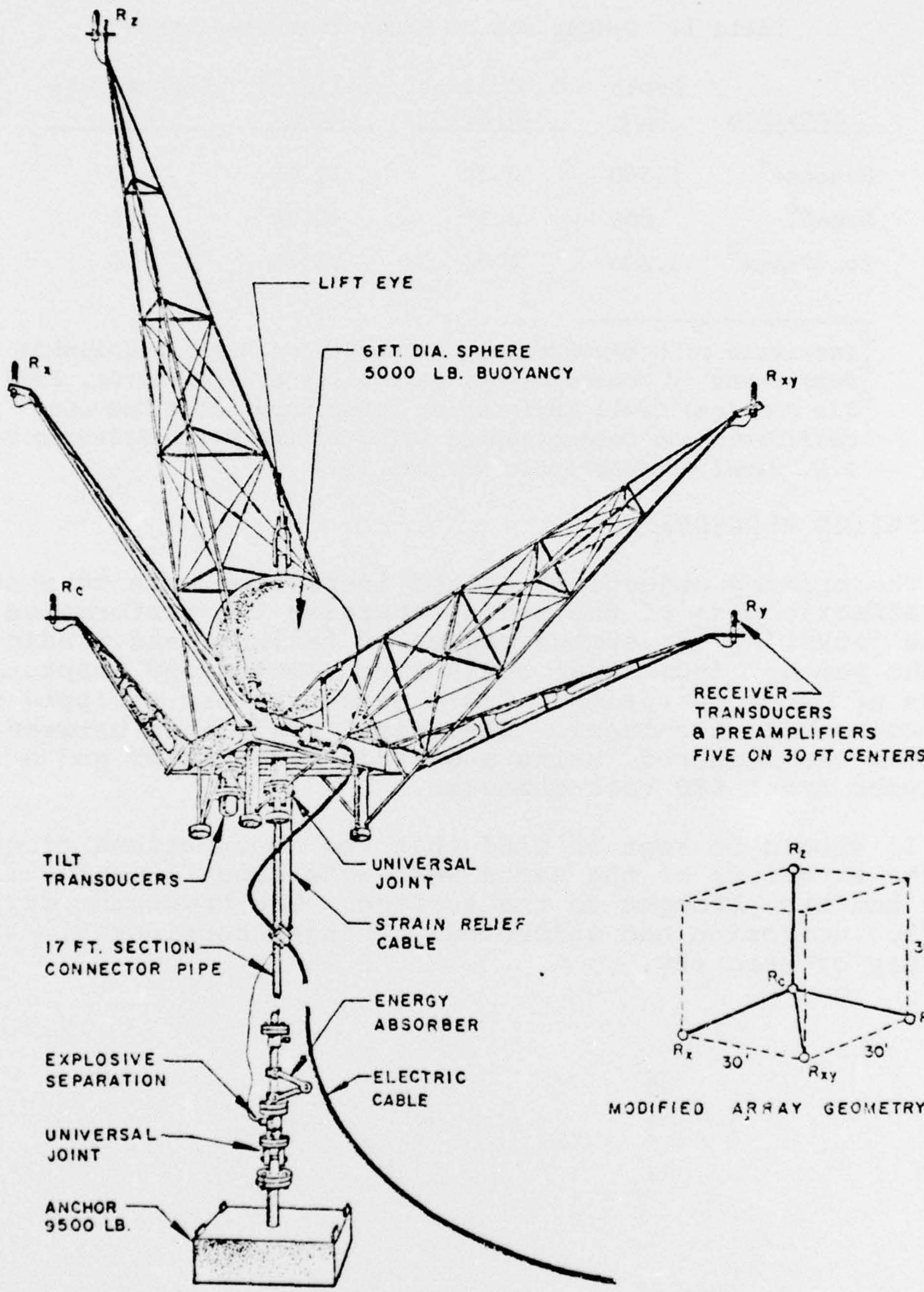

Figure 2. Buoyant Array, St. Croix

Table 1. Comparison of Range Characteristics

Location	Depth (ft)	O_2 Content (ml/l)	Salinity (ppt)	Temperature (°C)
Nanoose[a]	1,300	3.38	31.01	8.7
Dabob[b]	600	3.57	30.64	9.8
St. Croix[c]	3,300	4.00	35.00	5.6

[a] *Institute of Oceanography, University of British Columbia, 1968*
[b] *Department of Oceanography, University of Washington, 1966*
[c] *Jim Jenkins, Civil Engineering Laboratory, Port Hueneme, California and Oceanographic Atlas of the North Atlantic Ocean, U.S. Naval Oceanographic Office, 1967*

INSPECTION PROCEDURE

The primary objectives of the inspection were to evaluate the effectiveness of the seals, appraise the performance of cable jacketing, determine causes of failure, and predict life of the parts. Individual seals were removed and inspected for signs of water intrusion. Cable jacketing was stripped to determine watertightness. Electrical resistance between conductors was measured, using a GR-1864 megohmmeter and a Weston analyzer model 980 Volt-ohmmeter.

It should be kept in mind that the observations of corrosion on the exteriors of the parts were made about 3 months after they had been brought to the surface. The character of the surface corrosion had undoubtedly changed considerably since the day of recovery.

2. ARRAY 7

RECOVERY

Array 7 was recovered in September 1976 because of faulty preamplifiers in the c and x hydrophones. The array had been planted in June 1970 at a depth of 3,283 feet. The array parts arrived at NAVTORPSTA in good condition with no apparent damage, although the bottom of the outer shipping box was broken. The parts received were the junction box with the main cable seal, the c, x, y, and xy hydrophones, and the UQC hydrophones. The z hydrophone was missing.

INSPECTION

The array parts were generally free of marine growth. Photographs taken at St. Croix at the time of recovery indicate that, except for some small hydroids, little growth was present.

Junction Box. The junction box was heavily corroded on the exterior, with yellow powdery corrosion products accumulated around the Morrison seals of the hydrophone breakout end. See Figure 3. The end plate of the hydrophone side was removed

Figure 3. Exterior Corrosion, Junction Box, Array 7 (Approx. life size)

first. Very little corrosion was evident at the sealing surface to the first O-ring. The O-rings had a moderate amount of grease on them, as can be seen in Figure 4. The inside surface of the end plate had a dull green coating which, a discussion with APL personnel indicated, was a proprietary dichromate sealing finish used on zinc-plated surfaces.

Figure 4. End Plate O-rings, Junction Box, Array 7 (Enlarged)

The O-ring surface of the mating housing surface was lightly corroded in spots up to the first O-ring. No corrosion was found on the interior side of the first O-ring, indicating that no water got beyond that seal. The end plate at the main cable end of the junction box was removed. Again corrosion had reached only to the first O-ring of the double O-ring seal. The O-rings were lubricated with a moderate amount of grease.

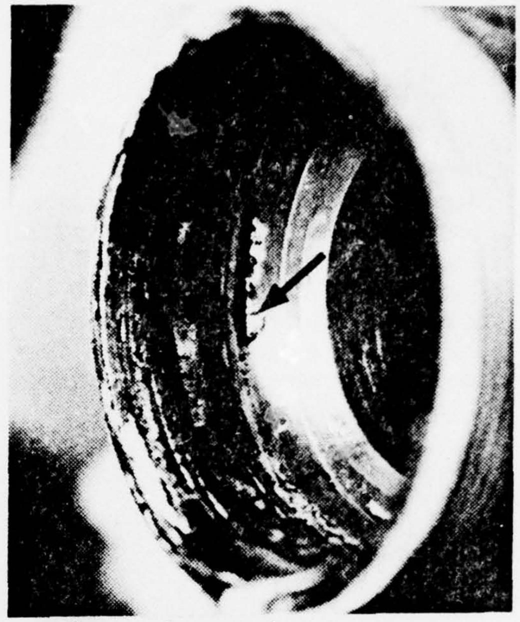

Figure 5. O-ring Surface, Main Cable Seal (Approx. life size)

Morrison Seals. The Morrison seal of the main cable was inspected. The O-ring seal of the Morrison seal body was corroded to a maximum depth of 1.241 inches at one point, which is beyond the second O-ring; however, no water was found in the seal area (see Figure 5). The O-rings were fairly heavily greased. The grease on the outer O-ring had become a chalky white due to exposure to seawater. This condition has also been observed on components recovered at NAVTORPSTA ranges. The O-ring squeeze was found to be about 12 to 13 per cent, which was about one-half that of the squeeze at the preamplifier seals. The observed dimensions were found to be in accordance with a detailed drawing of the part.

The back-up washer at the face of the first Morrison seal was slightly off center, causing the seal to extrude slightly at one side. (See Figure 6). Water which apparently entered along the gland wall, was found under the third main seal. Corrosion depth in the Morrison seal gland was 1.724 inches from the top of the gland. The corrosion line reached to the middle of the third seal. Water was also found at the solder cup, where the cable shield is attached to a feed-through pin.

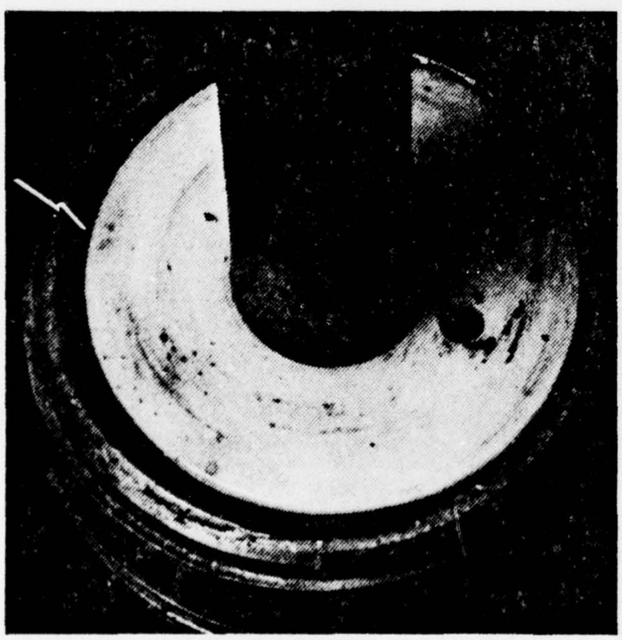

Figure 6. Extruded Seal, Main Cable Seal (Approx. life size)

Personnel present during the recovery operation explained that the method for transport of recovered arrays was to cut the cable at the array, re-submerge the array below a tow ship, proceed toward shore until the array hit bottom and at that point "store" the array until it could be raised again for dismantling.

The water found in the solder cup evidently entered the severed end of the cable during re-submergence. Supporting this observation, water was found along the complete length of the cable stub attached to the seal.

The interconnect cable Morrison seals at the junction box were disassembled and inspected. Of primary interest was the depth of the corrosion in the glands. The depth of a complete seal is 2.450 inches. The average corrosion depth as measured in six glands was 1.278 inches. The deepest corrosion was 1.683 inches to a point on the gland wall beyond the third seal. It is interesting to note that the spare hole, sealed with O-rings on a metal plug, was corroded only to the chamfer at the hole entrance. The spare hole is at the 2 o'clock position in Figure 7.

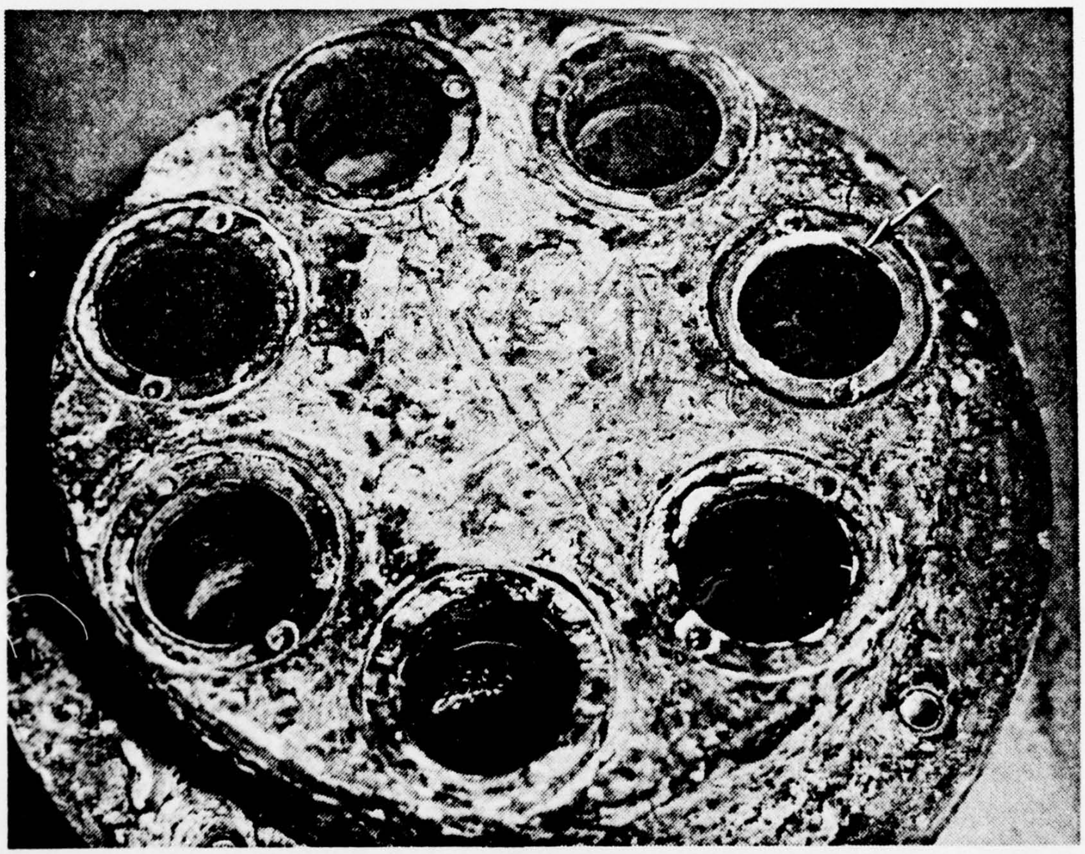

Figure 7. Morrison Seal Glands, Junction Box, Array 7 (Approx. life size)

The average corrosion depth in the five Morrison seals at the preamplifiers was 1.787 inches, the deepest being 2.095 inches. This is about 1/2-inch deeper than the corrosion of the glands at the junction box. The outer diameters of the seals and inner diameter of the respective glands were compared. The differences in diametric seal interference did not directly correlate with the differences in depth of corrosion in the gland.

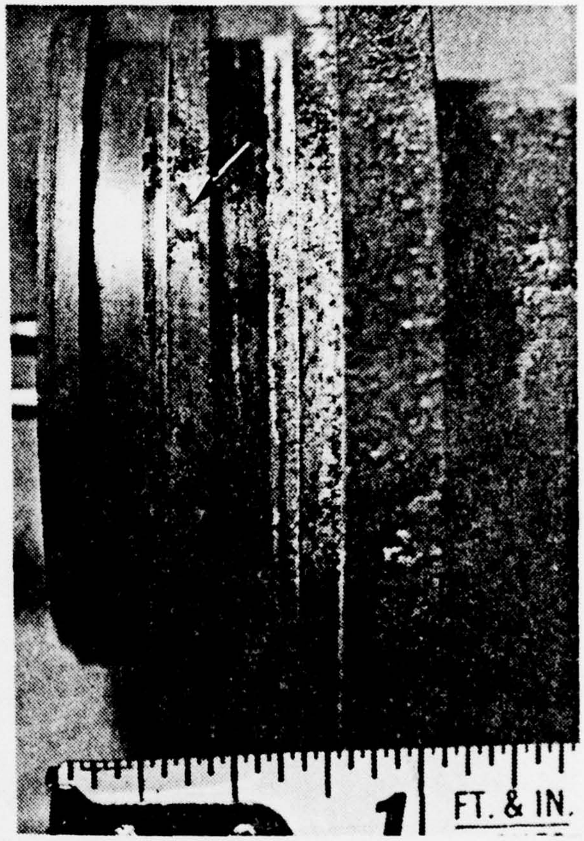

Figure 8. Corrosion Between O-rings, X Preamplifier Cable Seal End Cap (Enlarged 2X approx.)

<u>Preamplifiers</u>. No water leaked beyond the second O-ring of any of the preamplifiers. However, some moisture had leaked past the first O-ring of the cable seal end caps. This was evidenced by slight corrosion of the surface between the two O-rings of the cable seal end caps of the c, x, xy, and UQC preamplifiers. Figure 8, a photograph of the x preamplifier cable seal end cap shows this condition. The hydrophone end of the preamp is capped by a similar double O-ring seal. These showed no leakage past the first O-ring in any of the preamplifiers. Figure 9 is a photograph of the x preamplifier hydrophone end cap seal. The scratches on the lands were made during disassembly. It was noted that the O-ring surfaces of the end caps had two types of finishes: some the dull green type mentioned earlier, and the others a bright gold type. The bright gold-colored surface is a sodium dichromate seal finish used on zinc plate. There appeared to be no difference in corrosion protection between the two types of finish.

The O-ring squeeze of the preamplifier seals was determined by measuring the outboard groove/gland dimensions and the corresponding O-ring dimensions. The average squeeze was about 23 per cent on the cable seal end and 24 per cent on the hydrophone end. The lubrication, or amount of grease, on the O-rings on both ends appeared to be about equal. All O-rings had back-up rings.

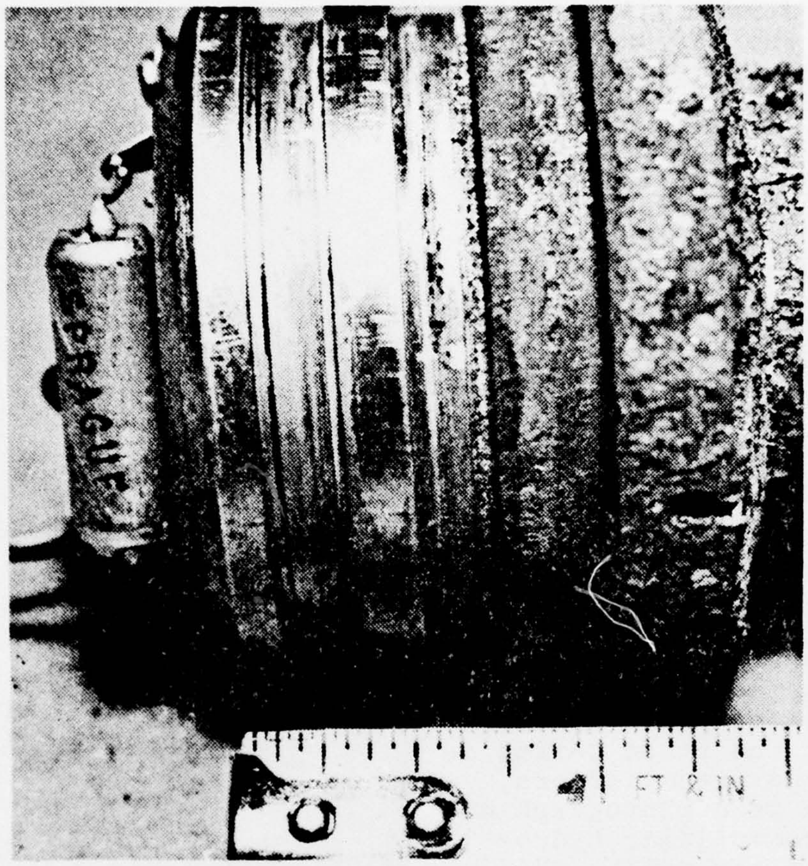

Figure 9. O-ring Seal Surface, X Preamplifier Hydrophone End Cap (Enlarged 2X approx.)

Interconnect Cables. The interconnect cables were a coaxial type similar to RG-58. The jacket was a black high-density polyethylene about 0.075-inch thick. The shield was tinned copper laid over a teflon inner dielectric. The center conductor was a silver-coated, stranded copper wire. The cables were cut open to determine the condition of the conductors. Table 2 below shows the results of the inspection. The corrosion of the shield did not result from jacket leaks. The leaks occurred at the seals primarily at the preamplifier end. Voids in the jacket were also seen at the interface of the shield and jacket. Figure 10 is a photomicrograph of a cross section of a void in the jacket. These apparently did no harm as no leaks could be attributed to them. A red fluid was also found in various sections of the inner conductor, but did not appear to be detrimental to the cable function. No attempt was made to determine its composition.

Table 2. Cable Condition

Preamp	Cable End	Remarks
x	preamp	Shield corroded along 118-inch section starting at seal. Center conductor okay.
x	j-box	Shield and center conductor uncorroded.
y	preamp	Shield corroded along 6-inch section from seal. Center conductor uncorroded but contained a red fluid under the insulation.
y	j-box	Shield and center conductor uncorroded.
xy	preamp	Shield corroded a distance of about 10 inches from seal. No corrosion in center conductor.
xy	j-box	Shield and center conductor uncorroded.
z	preamp	Shield corroded a distance of 33 inches from seal end.
z	j-box	Shield and center conductor uncorroded.
c	both ends	Shield and center conductor uncorroded.
UQC	preamp	Shield corroded and wet. Center conductor contained red fluid.
UQC	j-box	Shield dull and center conductor contained red fluid.

Figure 10. Void in Interconnect Cable Jacket (Enlarged 9X approx.)

ARRAY 7 FAILURES

The array was recovered because of malfunctioning of the c and x preamplifiers. Bench tests of the c preamplifier indicated its failure was due to an open in the base of the first input transistor, Q1, a 2N2484. The transistor can was cut open and it was found that the lead to the base junction of the transistor had melted, thus creating an open to the base. See Figure 11. The failure of the x hydrophone was not

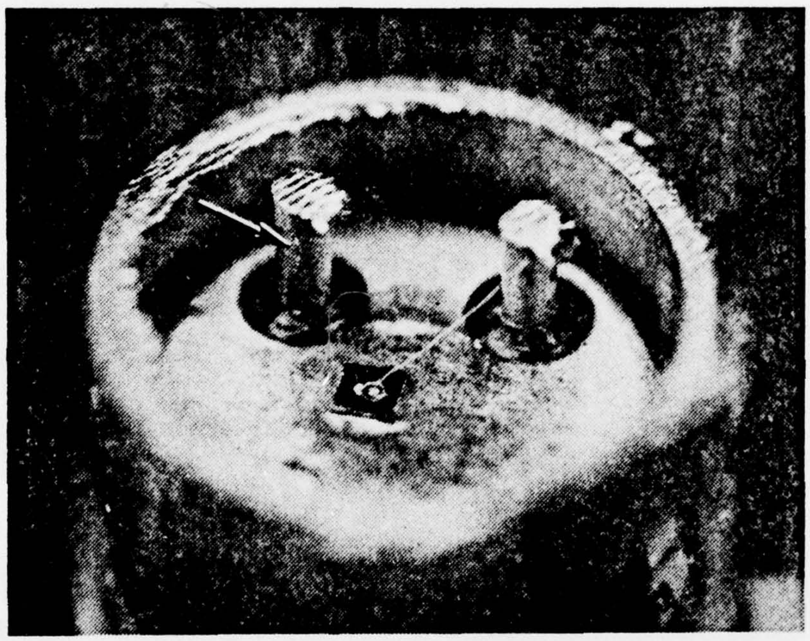

Figure 11. Open Contact in Q1 Transistor (Enlarged 19X approx.)

so clear cut. The preamplifier was tested on a bench but no malfunction was apparent. However, the interconnect cable had a resistance of 29k ohms between shield and center conductor prior to disassembly of the housing. With the ohmmeter polarity reversed, the resistance was 52k ohms. This difference indicates a small battery action which occurs with seawater leakage. This resistance was taken after the cable and seals had been out of the water for 3 months; the resistance when the array was in the sea is not known. Corrosion in the seal gland at the preamplifier indicated that moisture had reached the point where the center conductor and shield are separated just ahead of the last seal. This is shown as A in Figure 12. Moisture at that point resulted in a conductive path between the two conductors. The effect could range from no signal to a very noisy signal from the preamplifier depending upon the resistance of the path.

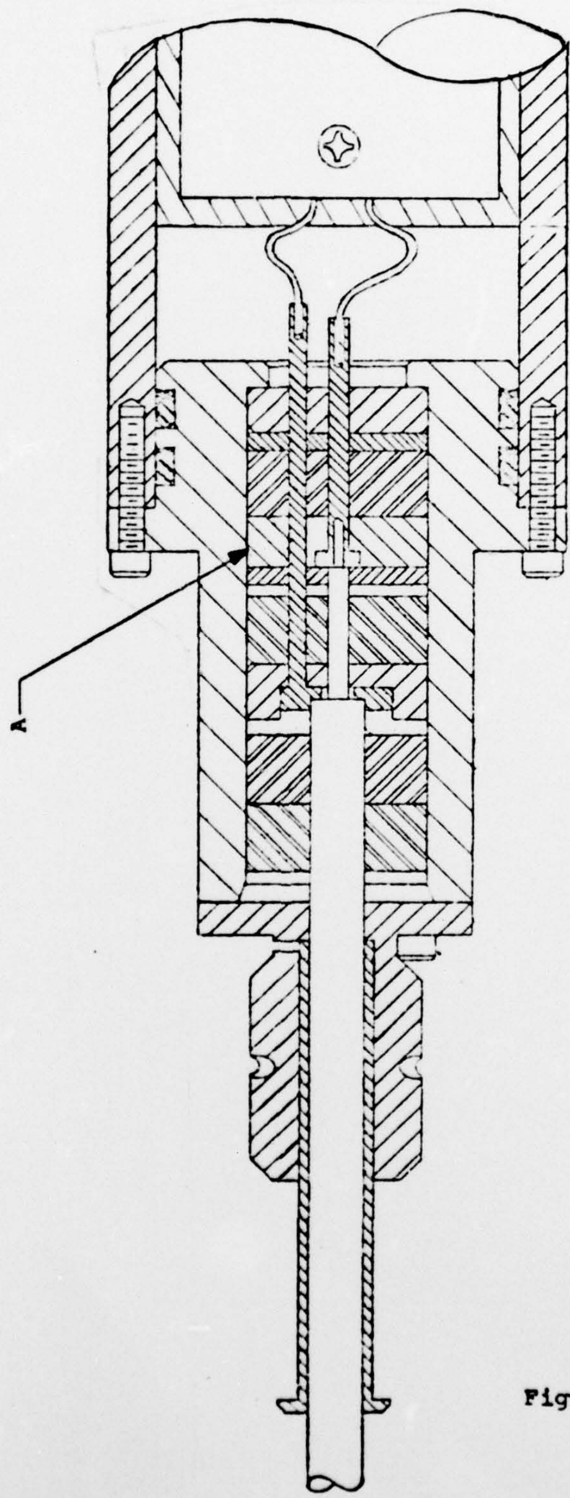

Figure 12. Corrosion Area,
Morrison Seal

3. ARRAY 10

RECOVERY

Array 10 was recovered on September 1976 because of faulty tilt and tracking signals. The array was originally planted in January 1967. The array parts, consisting of a junction box, tilt housing, and five preamplifiers were uncrated in good condition. The tilt, z preamplifier and explosive link cables had been cut off. However, the other four preamplifier cables were intact.

INSPECTION

The exteriors of the housings were heavily corroded. There was no evidence of marine growth on the components as received at NAVTORPSTA. However, a close-up photograph taken at the recovery site shows several hydroids growing on the leveling shackle located at the base of the flotation sphere.

Figure 13. Tilt Housing, Array 10 (0.23X approx.)

Figure 14. Hold-Down Screw on Tilt Housing (Enlarged 2¼X approx.)

Tilt Housing. The exterior of the housing was heavily corroded with red-brown to yellow-brown layers. See Figure 13. However, the 3/8-16" stainless-steel hold-down screws were uncorroded; see Figure 14. On removal of the housing cover, about

3 to 4 ounces of oil spilled out. The oil had come from the two pendulum housings (behind the circuit boards). The oil acts as a damping fluid for the tilt pendulums. The tilt housing had been shipped in an inverted position and the oil leaked through the synchro transmitters which are mounted on the housing above the normal oil level. A visual inspection of the tilt circuit board revealed no defects. The circuit was powered up on the bench and the output signal observed on a Tektronix 545 oscilloscope. The output at the cable terminals with the pendulums in a level attitude was a 20-kHz sine wave on a pulsed frequency of 588 Hz. The peak-to-peak output level was about 3 volts with 28 volts dc power. See Figure 15. The lower sawtooth wave is the output of the unmodulated synchro transmitter. Operation of the tilt circuit appeared normal. As a comparison Figure 16 shows the output as was seen at the computer site at St. Croix when the array was still on the range.

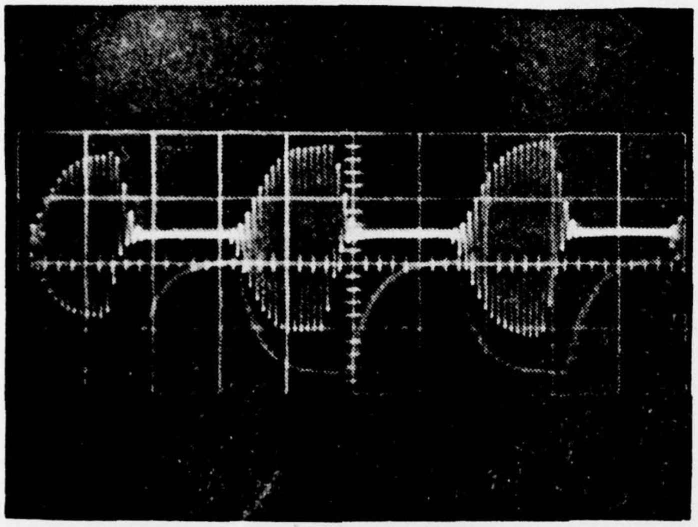

Figure 15. Tilt Output Waveform Observed in Bench Test

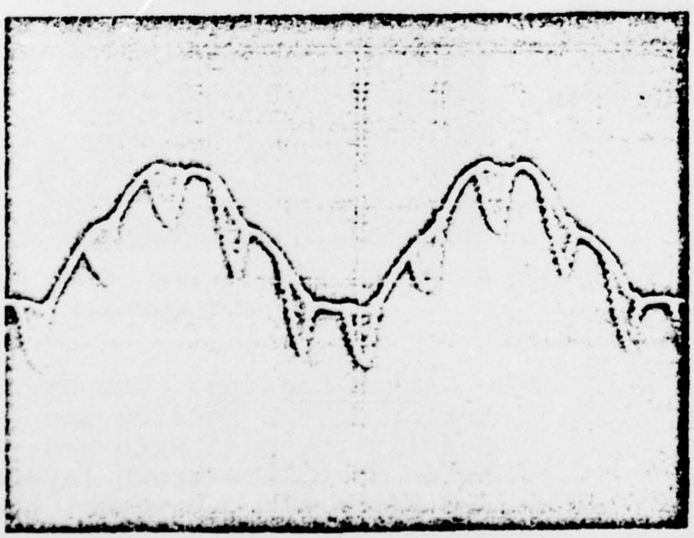

Figure 16. Tilt Output Observed at St. Croix

<u>Main Junction Box.</u> The main junction box exterior was heavily corroded with red rust and a yellow powdery residue around the interconnect cable seals. The j-box housing was oil filled, which is unusual. Some corrosion was noted in the interior at the interconnect cable end plate and on the housing wall, which had two dime-size spots. These corrosion areas appeared to be isolated and not a result of a seawater leak.

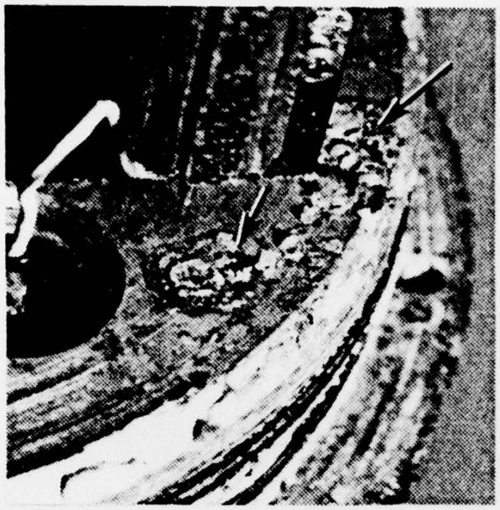

Figure 17. Corrosion on End Plate, Main Junction Box (Enlarged)

Figure 18. Corrosion in Housing, Main Junction Box (Enlarged)

(See Figures 17 and 18.) A corrosion spot was also seen on the printed circuit board which was mounted on standoffs on the end plate. (See Figure 19.) This indicates that some moisture may have been in the oil at the time of installation. The double O-ring seals of the end plates were heavily greased. Some corrosion was evident in the O-ring grooves but was irregular; see Figure 20. Seawater corrosion of O-ring surfaces ordinarily advances along a line roughly parallel to the grooves, as in Figure 21.

Preamplifiers. The preamplifier housings were encrusted with fairly uniform layers of red rust. Some crevices and corners contained a yellow powdery corrosion product. The housing interiors had no evidence of seawater leakage. Corrosion at the seals progressed up to the first O-ring in all cases as shown in Figure 21. This was expected since water is normally present up to that point. In cases where the O-ring is heavily greased the excess grease will fill the void between the plug and gland to prevent intrusion of water for some time. This delays corrosion of the O-ring surface.

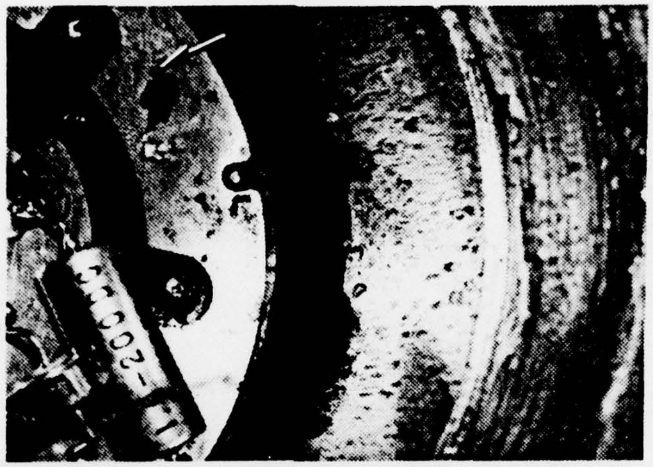

Figure 19. Corrosion on Circuit Board, Main Junction Box (Enlarged)

Figure 20. Corrosion of O-ring Surfaces, Main Cable End Plate (Enlarged)

Figure 21. Corrosion of O-ring Surface, C Preamplifier Cable Seal (Enlarged 1.5X)

In the case of the x preamplifier cable seal end cap, corrosion reached the second O-ring (see Figure 22). The O-ring glands of the housings were corroded to the depths corresponding to the corrosion on the plugs, as shown in Figure 23 for the c preamplifier. The c preamplifier had a ruptured capacitor (Figure 24) in the tuning circuit. This was a 0.1-microfarad capacitor rated at 200 Vdc. It provided ac ground to seawater on the secondary side of the hydrophone tuning circuit to prevent oscillation in the preamplifier circuit. The failure is believed to have been caused by the high voltage surge of a lightning strike. Strikes had occurred in 1968 and 1973. The resistance across the damaged capacitor was 1 megohm. This would not have materially affected functioning of the preamplifier.

Figure 22. Corrosion of O-ring Surface, X Preamplifier Cable Seal (Enlarged 2X)

Morrison Seals. A total of 13 Morrison seals were inspected including one on the main cable; seven on the interconnect cables at the junction box, and one on each of five preamplifiers. The corrosion in the gland of the main cable seal had progressed 1.238 inches into the seal to the point at which the shield is soldered to a feed-through pin. Figure 25 is a photograph of the seal, whose overall length was 2.4 inches. Water was found at the shield termination but little corrosion had occurred there. Since the main cable had been cut and the array subsequently re-submerged for towing to shore, the water probably entered along the shield from the cut. However, the corrosion path along the gland wall indicates that some water entered at the wall.

The copper foil of the shield on the main cable was corroded along its full length, about 10 feet, indicating the presence of water. No evidence of water leakage was seen beyond the second seal. The assembly of the seal differed from current

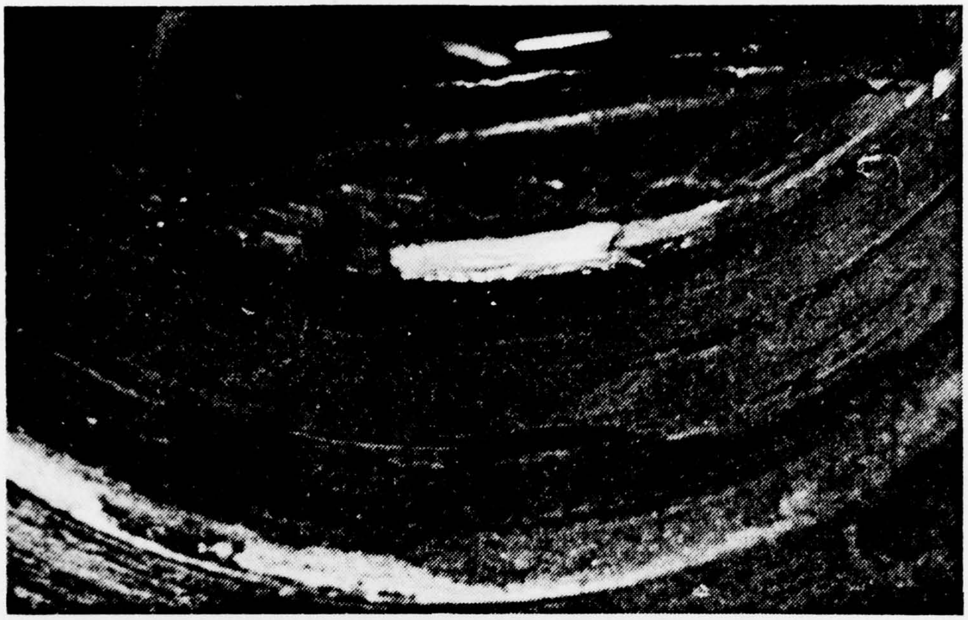

Figure 23. Corrosion of O-ring Gland, C Preamplifier Housing (Enlarged)

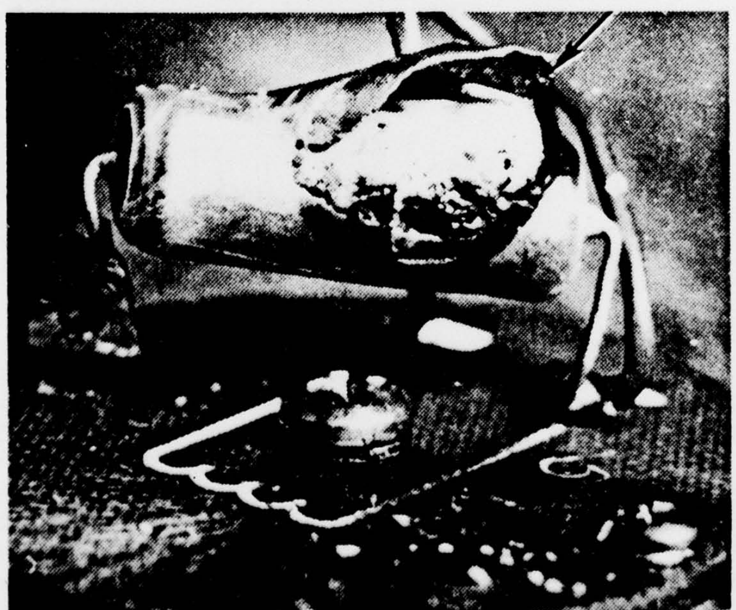

Figure 24. Ruptured Capacitor, C Preamplifier (Enlarged)

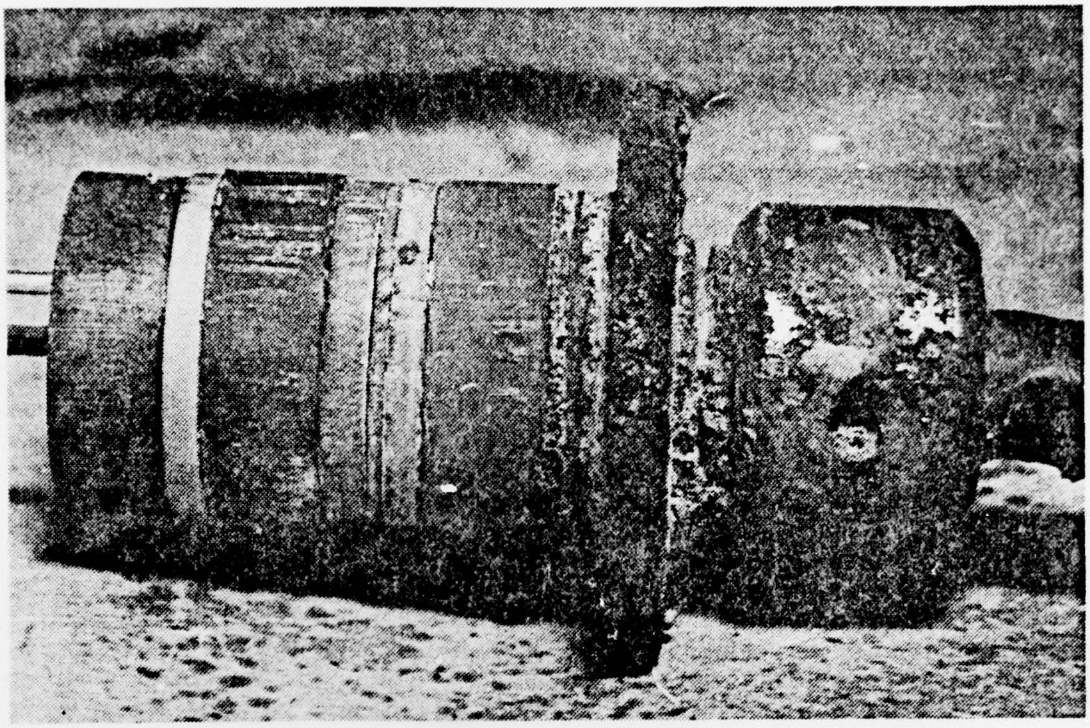

Figure 25. Main Cable Seal, Array 10 (Approx. life size)

practice in that the cable armor wires were terminated about 10 feet short of the junction box in a lead-filled steel collar. The conductors then continued to the junction box seal through a protective rubber hose.

The Morrison seals of the interconnect cables at the junction box were inspected. The average corrosion depth along the gland walls on seven seals was 0.839 inches. The depth of a complete seal is 2 3/8 inches. The deepest penetration was 1.075 inches (in the c preamplifier seal), reaching the area of the shield breakout point where the shield is soldered to a feed-through pin. Seawater at this point would create an electrical path between shield and ground. The lowest resistance measured was 59k ohms between shield and case at the x preamplifier. This resistance is not low enough to cause a signal or circuit failure; however, it could cause a very small amount of electrolysis. The average corrosion depth in the Morrison seals at the five preamplifiers was 0.904 inches; the deepest at 1.005 inches. This is about the same depth as the corrosion in the junction box seals.

Interconnect Cable. The interconnect cable was a coaxial type similar to RG-58. The jacket material was polyurethane and the underlying shield a braided, tinned copper wire. The dielectric was polyurethane extruded over a stranded center conductor. Close examination revealed transverse cracks in the jackets of all the interconnect cables. The cracks became evident on the outside radius as the cable was formed into a small-radius loop (see Figure 26). In most cases the cracks did not completely penetrate the jacket; however, in the cases where the cracks did penetrate it was not obvious that water had entered to the shield. The shield was not badly corroded as would have been the case if the jacket had leaked. This indicates that the cracks appeared during or after recovery and were caused by flexing of the cabling. It appears that the plasticizer in the polyurethane leached out, leaving the material brittle in spots. The cracks did not appear to be localized to any particular area of the cables and apparently were not related to cable placement on the array.

Hydrophone Seals and Transducer. The rubber boots sealing the transducer mounted atop the preamplifiers were inspected. All five hydrophones evidenced water leakage to the O-ring from the wire-wrapped seal at the base of the boot. Figure 27 is a photograph of the xy hydrophone without the boot, which fits over the O-ring and the rounded flange at the base of the

Figure 26. Jacket Cracks, Interconnect Cable (Enlarged 8X approx.)

transducer. The boot is secured below the rounded flange with a double wrap of stainless steel wire. The wire in no case showed evidence of deterioration. Evidence of water leakage past the O-ring was present on the c, y, and z hydrophones, although no moisture was visible. The c hydrophone had the "highest" watermark and is shown in Figure 28. Electrical resistance between the hydrophone and case was about 1 megohm, which again would probably not affect operation of the hydrophone. It was noted that the surfaces of the transducers were dry upon removal of the boot. The practice at NAVTORPSTA is to use transducer oil in the boot to facilitate assembly and to preclude air under the boot. The oil also helps prevent intrusion of water.

Figure 27. XY Hydrophone, Boot Removed (Enlarged 1.4X approx.)

Figure 28. Watermark on Lower Side of Sphere, C Hydrophone (Enlarged 1.4X approx.)

ARRAY 10 FAILURES

The faulty tilt signal originally noted was not evident in a bench test. However, information from recovery personnel indicates that the main cable leading to the array was defective. The section between the in-line amplifier and the array was replaced when the new array was planted. Poor signal conditions are a typical result of low resistances between conductors in the main cable. The signal waveform observed at St. Croix, (Figure 16), may be the tracking signal superimposed on a full-wave rectified 60-Hz line ripple. The frequency of the larger amplitude signal is about 120 Hz and the frequency of the smaller wave about 20 kHz. The clipped appearance of the 20 kHz, which contains tilt information, may be caused by a power-starved amplifier, which could result from a bad cable.

4. CONCLUSIONS

ARRAY 7

The malfunction of the c preamplifier was due to an open in the base junction contact of the Q1 input transistor. The x preamplifier failure most probably was due to a low-resistance path between the shield and center conductor. Crevice corrosion at the seal gland progressed past three rubber seals into an area where seawater created a conductive path between the conductors.

The O-ring seals held up well except for the seal at the main cable entry in the junction box. Corrosion was found beyond the second O-ring in that seal, whereas little to no corrosion was seen beyond the first O-ring in the other seals. The main cable seal had a 12 per cent squeeze versus a 23 per cent squeeze on the O-rings at the preamplifiers. The leak past the second O-ring is attributed to the lower squeeze. Corrosion in the Morrison seal glands had reached an average of 1/2 to 3/4 of the total length of the seal at the junction box and preamplifiers respectively. Differences in seal interference fit did not account for the difference in corrosion depth.

The polyethylene-jacketed interconnect cable held up well. The shield showed slight corrosion in some cases at the terminations where some moisture got through the seals.

The life of array 7 apparently was approaching its limit as indicated by corrosion in the seal glands. The failure of the x preamplifier appears to have been caused by seawater intrusion into the cable seal. This type of failure is exhibited by a gradual degradation of the tracking signal and a decreasing electrical resistance between shield and seawater ground. Arrays of similar design and age should be showing these indications now and if not will do so within two to three years.

ARRAY 10

The cause of the tilt circuit failure could not be determined. In a bench test at NAVTORPSTA the circuit functioned normally. However, during array replacement at St. Croix, a portion of the main cable indicated low resistance readings and was replaced. This section of cable could have been the cause of the bad tilt and tracking signals received at the computer site.

Lightning damage was apparent in the c preamplifier, which sustained a burned grounding capacitor at the secondary of the hydrophone tuning transformer.

The Morrison seal glands of the interconnect cables showed water intrusion to an average of about one-third the length of the seal. The Morrison seal of the main cable had water leakage to its midpoint. The O-ring seals in the worst case showed slight corrosion between the redundant O-rings. In most cases corrosion did not extend beyond the first O-ring.

The polyurethane jacket of the coaxial interconnect cable cracked when a small loop was formed, indicating loss of plasticizer in the jacket material. The cracks apparently were not present when the array was on range, since the shield was not corroded in areas where the cracks penetrated the jacket completely.

Three of the five hydrophones showed evidence of water leakage at the boot. Watermarks were visible on the transducer elements above the mounting pedestal.

It is estimated that the additional life of this type of array will be about 3 years.

The crevice corrosion in the Morrison seal glands went deeper on array 7 than in array 10 although array 10 had been in service 117 months compared with 76 months for array 7. Some difference in construction of the seals was noted. The older array 10 seal used hard rubber back-up washers behind each seal, whereas the array 7 seals used nylon back-up washers. Also the rubber seals were slightly harder in array 10, which had a shore A of 43. The array 7 seals had a shore A of 35. No analysis of the metal in the seal glands was done. The reason for the difference in corrosion rates was not determined.

5. RECOMMENDATIONS

1. The only leak past a double O-ring occurred where the O-ring squeeze was 12 per cent versus 23 per cent at other O-ring seals. It is recommended that the higher squeeze be used to achieve a longer service life.

2. The type of polyurethane-jacketed coaxial cable used on array 10 should not be used for long-term submergence applications.

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