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Technical Note N-978

SURVEILLANCE SYSTEM FOR WATER STORAGE TANKS

by

Richard W. Drisko, Ph. D.

August 1968

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NAVAL CIVIL ENGINEERING LABORATORY
Port Hueneme, California

SURVEILLANCE SYSTEM FOR WATER STORAGE TANKS

Technical Note N-978

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Richard W. Drisko, Ph. D.

ABSTRACT

A surveillance system for monitoring tank-to-water potentials in cathodically-protected water storage tanks was fabricated under contract and installed and tested in a tank at CBC, Port Hueneme, California. After very minor modifications the system performed well for a two year period.

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INTRODUCTION

The water storage tank is one of the most commonly found structures throughout the Naval Shore Establishment. Because of difficulties encountered at a number of field activities in obtaining the desired level of protection from corrosion for steel tank interiors from currently used coating and cathodic protection systems, the Naval Facilities Engineering Command directed the U. S. Naval Civil Engineering Laboratory to conduct a survey to determine the type of corrosion and maintenance problems existing in the interiors of water storage tanks and make recommendations for further investigations in this area. One of the findings of this survey* was that because very few water storage tanks are inspected on a regular schedule, very little is known about the condition of their interiors. Consequently, it was recommended that NCEL study the feasibility and different uses of a permanent system for measuring tank-to-water potentials from a ground level. This study was to be directed at determining the usefulness of such a system not only by itself but in conjunction with a cathodic protection system designed to automatically provide the desired level of protection. This report describes the results of testing the surveillance system.

BACKGROUND

Many of the cathodically protected water storage tanks in the Naval Shore Establishment are elevated, and thus Public Works personnel desiring to determine tank-to-water potentials must climb them while carrying their necessary equipment. By installing in water tanks one or more permanent reference half-cells and cables leading to ground level, it would be unnecessary to climb the tank for this purpose. Several half-cells would be necessary to determine the electrical potential profile of the tank interior.

* U. S. Naval Civil Engineering Laboratory. Technical Note N-714: Survey of water tank interiors, by R. W. Drisko, Port Hueneme, Calif., 3 May 1965.

A ground level, 420,000 gallon, cylindrical water storage tank at CBC, Port Hueneme, was made available for use in the surveillance study by the Public Works Office there. This bolted steel tank, 24 feet high and 55 feet in diameter, is coated on the interior with coal tar and is cathodically protected with a system using silicon-iron anodes and impressed current. The coal tar coating is badly blistered in places but very little current is required for cathodic protection. The water in this tank comes from two different sources and is a blend of these waters so that it has variable composition, but the total solids are always quite high (about 650 ppm), and the temperature of the stored water remains relatively constant, around 65°F. The water is used mainly as a reserve supply for fire fighting and so is routinely stored for two weeks and then drained into the domestic water system and refilled. It is chlorinated so that it is suitable for potable use.

A contract for the design of the surveillance system and its installation in the above tank at CBC, Port Hueneme, was let to the Aerojet General Corporation, Azusa, California.

DESIGN OF THE SURVEILLANCE SYSTEM

The surveillance system was designed to utilize nine reference half-cells distributed inside the tank at three levels (Figure 1) with a pair of lead wires at each of these half-cells locations going through electrical conduits to a common switch box at ground level. One wire of each pair was connected to the half-cell and the other to a point on the tank interior at the half-cell location. A portable meter joined to the switch box could then indicate the electrical potential at any of the nine half-cell locations by activating the different switches one at a time. Thus a profile of electrical potential could be determined by use of the nine half-cells.

Reference Half-Cells

Silver/silver chloride reference half-cells were selected for the surveillance system because of their stability* over long periods of time. The variation of such cells with temperature is reported** to be less than one millivolt per degree centigrade.

Electrochemical potentials in aqueous solutions can be calculated from the simplified (25°C) Nernst equation:

*"Reference Electrodes," by D. J. G. Ives and G. J. Janz, Academic Press, New York, 1961, pp. 180-182.

** "Electrochemical Data," B. E. Conway, Elsevier Publishing Company, London, 1952, p. 297.

$$E = E_o - \frac{0.059}{n} \log \frac{C_{ox}}{C_{red}} \text{ where:}$$

E = half-cell potential, volts,

E_o = standard potential, volts

n = number of electrons exchanged per atom (valance change)

C_{ox} = concentration of oxidized form, moles per liter

C_{red} = concentration of reduced form, moles per liter

The reaction at the silver/silver chloride reference half-cell is shown below:

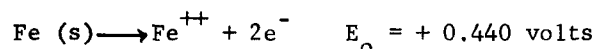


The standard potential for this reaction at 25°C is -0.222 volts in the direction to the right. It can be seen from the Nernst equation that the low chloride ion concentrations normally present in stored water would tend to increase the half-cell potential. Thus it is necessary to maintain this concentration within close limits if the half-cell is to serve as a stable reference electrode. This was accomplished by enclosing each silver/silver chloride unit in a ceramic diffusion jacket (Figure 2) and placing a high impedance in the electrochemical circuit that operates continuously between each half-cell and the tank wall. When potential measurements are taken, the meter automatically introduces a 10 megohm impedance across the cell, matching that normally present in the system. This permits the galvanic current to remain constant and thus maintains a steady state junction.

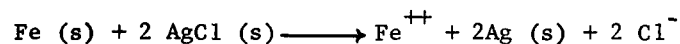
In normal operation the diffusion of chloride ions through the ceramic jacket is governed by the porosity of the jacket and the concentration gradient across it. An appreciable change in chloride ion concentration of the stored water will disturb the steady state condition, but a ten fold change in chloride ion concentration would be required for a 0.059 volt change in the half-cell potential. The continuous small flow of current through the high impedance in the system permits the generation of chloride ion at a rate proportional to the potential difference between the pair of half-cells. For example, at a potential difference of 0.724 volts, chloride ion would be generated at a rate of 6.48×10^{-8} equivalents per day (assuming 100% current efficiency). After a time a steady state should be reached at which the rate of diffusion of chloride ion through the semi-porous jacket will be the same as the rate of chloride ion generation. The consumption of silver chloride in this manner is so slight that the contractor estimates the life of the reference cell to be at least ten years.

With the high rate of chloride generation caused by the initial low concentration of chloride ion, the cell potential will tend to decrease and thus the chloride generation will tend to decrease. In this manner the system will become self-regulating. A similar situation occurs if the chloride ion concentration outside the semi-porous jacket is higher than that on the inside, except that diffusion will be inward rather than outward.

The electrochemical reactions taking place at the other half-cell (the tank wall) are considerably more complicated than is the case at the reference half-cell, but the potential produced is governed by the initial reaction:



The overall reaction establishing the corrosion potential is then:



The simplified Nernst equation for the overall reaction is:

$$E = E_o_{\text{Fe/Fe}^{++}} - E_o_{\text{Ag/AgCl}} \times \frac{.059}{2} \log (\text{Fe}^{++}) (\text{Cl}^{-})^2$$

Because of the irregular deterioration of the coating on the tank wall (Figure 3) and nonuniformities in the anode system, there will be different potentials measured at the nine different reference half-cell locations. The nine reference half-cells were installed in the tank to determine the magnitude of variation in electrical potential existing on different portions of the tank wall and the number that might be required in a surveillance system or automatically-controlled cathodic protection system.

Switch Box

The metal switch box (Figure 4) was designed to have a pair of insulated meter jacks and nine toggle switches so that electrical potentials at all nine half-cell locations could be measured from this one location. With the switches in the off position, there is a 10 megohm resistor across each cell. When the meter is connected to the system through jacks in the switch box, changing a switch from the off to the on position automatically removes a 10 megohm resistor in the switch box and inserts a ten megohm resistor in the meter in order to maintain a steady state junction. The high impedance of the system eliminates any lead length effects.

Reference half-cell number 5 is located inside the tank behind the switch box as shown in Figure 1. This eliminates the use of a junction box (Figure 5) as was required with the other half-cells. The switch box and junction boxes were fitted with water-tight gaskets to prevent leakage of stored water into them. Their covers were also gasketed to keep out moisture from the atmosphere.

Meter

The high impedance voltmeter used for measuring electrical potentials developed in the cell represented by the steel tank wall and the silver/silver chloride half-cell was designed to be pocket-size. It has a scale with a range of 100 mv and a series of range switches so that any 100 mv span up to 1600 mv can be selected. The sum of the values for each range switch activated and that of the scale reading is the potential being measured. The interconnecting cable between the meter and jacks in the switch box are color coded for proper polarity. Adjustments are present on the meter for periodic recalibration. Meter specifications are given below:

Size	1 x 3 x 5 inches
Input impedance	10 megohms
Resolution	1 mv
Components	solid state
Power Source	2- 15 v. batteries
Weight	15 oz.

INSTALLATION OF SYSTEM

The surveillance system was installed in the tank at CBC, Port Hueneme, by Public Works personnel under the instruction of a technical representative of the contractor who designed and fabricated the system. All the equipment was prefabricated with the exception of the conduit sections which required fitting in place.

First the switch box was installed on the tank interior about 4½ feet above the base of the tank. Then a hole was drilled through the tank wall and switch box for mounting electrode No. 5 to the tank interior. (See Figure 4). The other eight electrode locations were roughly spotted as shown in Figure 1. Starting from the switch box, the conduit sections were bent, cut, and joined to give the desired pattern. The junction boxes attached to the conduits were then mounted in place. The marked, shielded cables (two from each junction box) were carefully pulled into place and the lower ends soldered to the switch panel. Eight inches of extra length were provided for each cable to permit service removal of the junction box. Each remaining electrode was next installed and the proper connections made at each junction box (see Figure 5). The junction box and switch box covers were lastly secured in place to prevent moisture from entering the

system. Installation time with the two man crew was six hours. The cost of the actual hardware is about \$1,500 of which \$1,000 is for the portable meter.

TESTING OF SYSTEM

On checking the surveillance system the day after installation, the switch box was found to be full of water. Each junction box was filled with water also. It was found that the water had come through the half-cells and down the shielded cables. The braided electrical wires did not form a tight fit against the plastic sheath, and water was carried down each cable by capillary action. Attempts were made to seal the leaks with adhesive at each cable opening, but no permanent stoppage was obtained.

Determinations of tank-to-water potentials were made daily during the period of attempting to repair the leaks with adhesive. The half-cells performed quite well but switches in the box frequently shorted out when the box interior was wet. The contractor finally decided that it was necessary to replace the cables with ones that had strands of wire bonded tightly to their sheaths. At the same time the switches in the box were replaced with ones that were not moisture-sensitive. No further leakage problems have been encountered since these modifications. The contractor also replaced the reference half-cells with ones with an additional ceramic shell covering them (Figure 6) to filter out contaminants in the tank that might clog the smaller, inner porous cup.

The tank potential profile was measured daily and recorded on special data sheets as shown in Table 1 for the first four months after installation of the surveillance system. Later readings were taken about every three days (Table 2). The rectifier was adjusted so that potentials were usually slightly greater than -0.850 v. They were lowest just after the tank had been drained and refilled and then rose slightly and leveled off to a constant value (see Table 1). There were slight changes in the tank profile with time, but those half-cells that originally had the highest readings tended to remain the highest and those that had the lowest readings tended to remain the lowest. The variation in reading in each profile measurement was so small that one or two reference half-cells seem sufficient for incorporation into an automatically-controlled cathodic protection system. When the tank was only partially filled so that some of the half-cells were not covered with water, the values of potential at these locations were close to 0 while the others were very little affected. The conductivity of the water remained rather constant (about 1.3×10^{-5} mhos) and so had little effect on the readings. The variation in water temperature was also rather slight. Readings from the sunny side of the tank, however, tended to be very slightly higher than those taken from the shady side. The average level potential changed appreciably from time to time and required periodic adjustment of the rectifier to remain at the desired level. The amount of current required for complete protection (about $\frac{1}{2}$ amp) was so small that it was difficult to maintain a constant tank-to-water potential. Meter measurements from the nine half-cell locations

were verified by a standard calibrated silver/silver chloride electrode lowered into the water from the top and a standard potentiometer.

Several minor difficulties were encountered with the meter. If the off-on switch was not returned to the off position after readings were taken, the two dry cell batteries would be used up, and another pair would have to be soldered into place. A pressure sensitive switch would have been more desirable but because of the compact size of the meter, the replacement of the original switch with a pressure-sensitive one presented a major problem. The jacks in the meter for the interconnecting cable extending to the switch box were so close to each other that they sometimes touched and caused erroneous readings. This was corrected by separating the jacks further apart. One of the trimming potentiometers in the meter became damaged and had to be replaced. All in all the difficulties were mainly associated with intermittances resulting from limited mechanical tolerances in the very compact meter and were such as can be corrected in the design of an improved instrument.

After two years of service, one of the reference half-cells was removed and the two ceramic jackets were cut away from the silver/silver chloride electrode (Figure 7). The electrode had an original nominal diameter of 1/4-inch (63.5 mm), but an unused duplicate half-cell had a measured diameter of about 68 mm. The diameter of the half-cell removed after two years varied from 61 to 69 mm with an average of 64. This indicated that very little was consumed and confirms the estimated service life of at least ten years. The outer ceramic jacket was only very slightly stained and the inner ceramic cup was very clean, indicating that clogging of the pores was no significant problem. The removed electrode and another, unused one of similar construction were equilibrated in tap water for 5 days. The electrical potentials of these electrodes had leveled off fairly well by then, and they differed by only 6 millivolts.

Should floating ice occur in tanks with silver/silver chloride reference half-cells, it might be necessary to use a protective cage to prevent abrasion damage to these half-cells and locate the half-cells in a lower portion of the tanks.

CONCLUSIONS

1. The surveillance system performed well for a two year period, and continues to do so at this writing, after very minor modifications were made to the original system.
2. The reference silver/silver chloride half-cells were quite stable for the two year test period, and the contractor's estimate of a ten year service life for them seems realistic.
3. The meter had a number of minor imperfections that can be overcome by changes in design, but it was quite effective in producing accurate readings of tank-to-water potentials.

4. The surveillance system was effectively utilized to change rectifier settings so that the desired level of cathodic protection was maintained.

RECOMMENDATIONS

1. It is recommended that a surveillance system utilizing no more than two silver/silver chloride reference half-cells be installed on cathodically protected water storage tanks throughout the Naval Shore Establishment.
2. It is recommended that an automatically-controlled cathodic protection system with two reference silver/silver chloride reference half-cells be tested in a navy water storage tank.

ACKNOWLEDGEMENT

Personnel in the Public Works Office at CBC, Port Hueneme, were most cooperative in setting up the test program and draining the tank for periodic inspection and modifications.

Table 1. Water Tank Potentials in Volts*

Cell No.	Monday	Tuesday	Wednesday	Thursday	Friday
1	.887	.892	.894	.894	.896
2	.884	.888	.893	.894	.898
3	.862	.867	.872	.874	.878
4	.878	.883	.888	.888	.892
5	.850	.852	.855	.858	.860
6	.868	.872	.878	.879	.880
7	.875	.880	.884	.886	.885
8	.880	.885	.888	.891	.892
9	.881	.887	.889	.892	.894
Water Level 22.4'	Water Level 22.4'	Water Level 22.4'	Water Level 22.4'	Water Level 22.4'	Water Level 22.4'
Average .872	Average .874	Average .882	Average .884	Average .886	
Time 1130	Time 1400	Time 1400	Time 1130	Time 1130	

*All potential measurements are negative with respect to a standard hydrogen electrode.

Table 2. Water Tank Potentials in Volts*

Cell No.	Monday	Tuesday	Wednesday	Thursday	Friday
1	.822		.820		.824
2	.830		.829		.833
3	.827		.824		.829
4	.824		.821		.825
5	.815		.814		.819
6	.813		.811		.813
7	.802		.801		.805
8	.824		.822		.827
9	.821		.819		.824
Water Level 21'8"		Water Level	Water Level 21'8"	Water Level	Water Level 21'8"
Average .826		Average	Average .818	Average	Average .822
Time 1530		Time	Time 1130	Time	Time 1300

*All potential measurements are negative with respect to a standard hydrogen electrode.

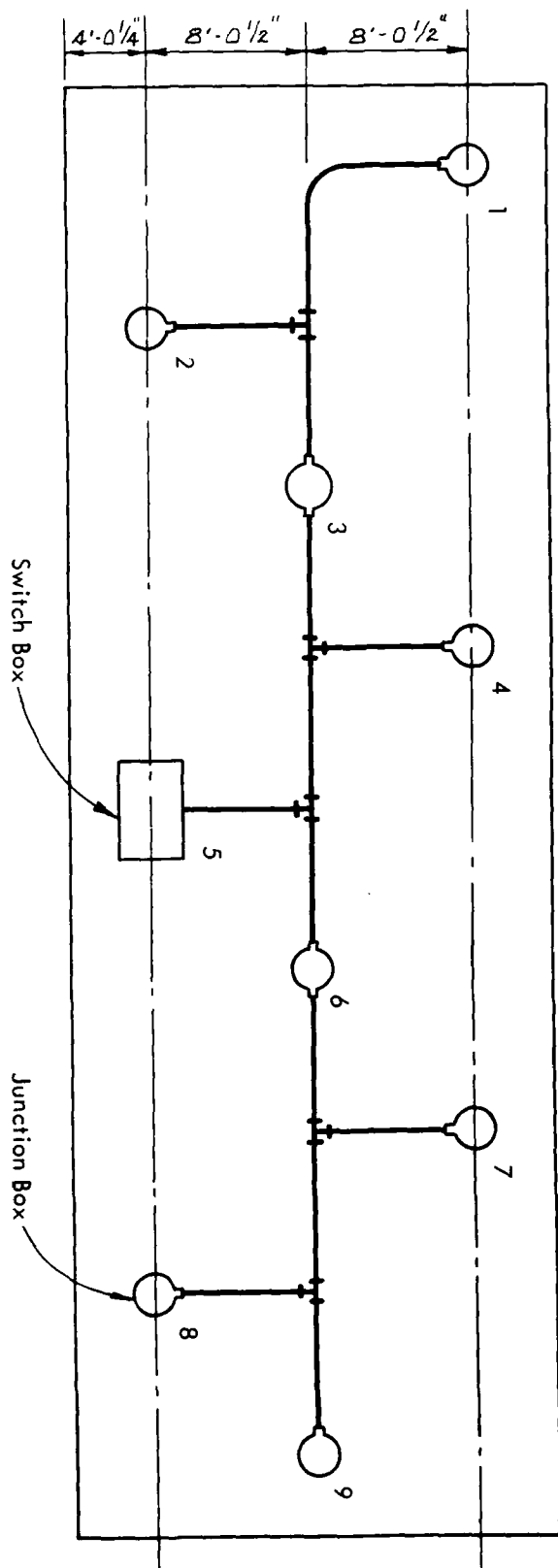


Figure 1. Flat pattern showing distribution of half-cell junction boxes on tank-wall and conduits leading to common switch box (not to scale).

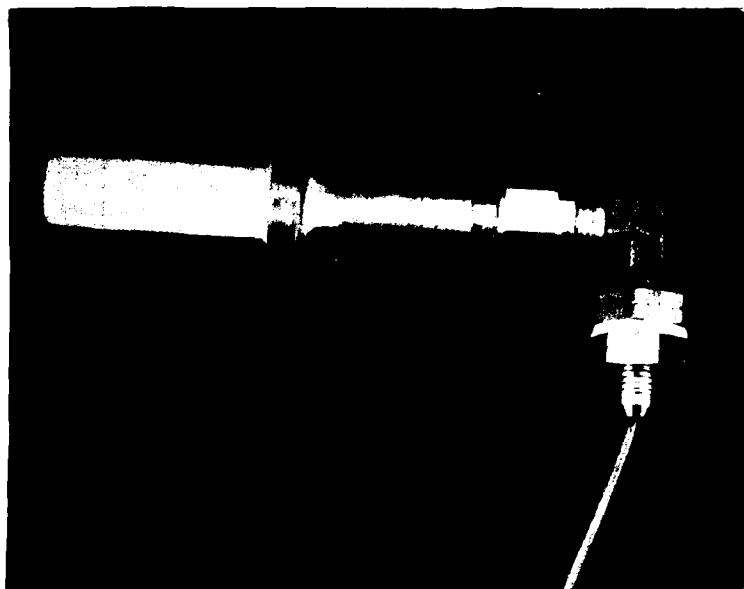


Figure 2. Reference silver/silver chloride half-cell unit.



Figure 3. Tank interior with blistered coal tar coating.

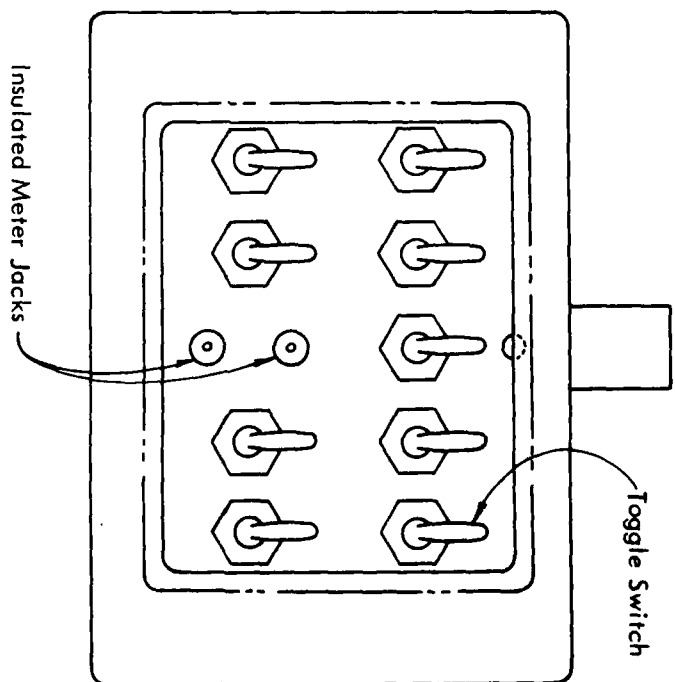
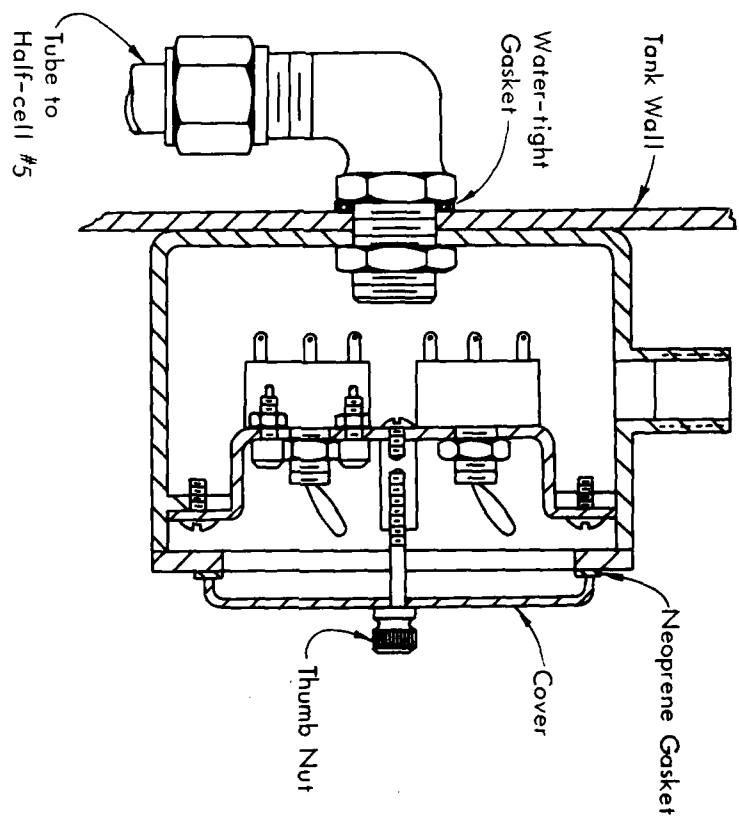


Figure 4. Switch box of surveillance system.

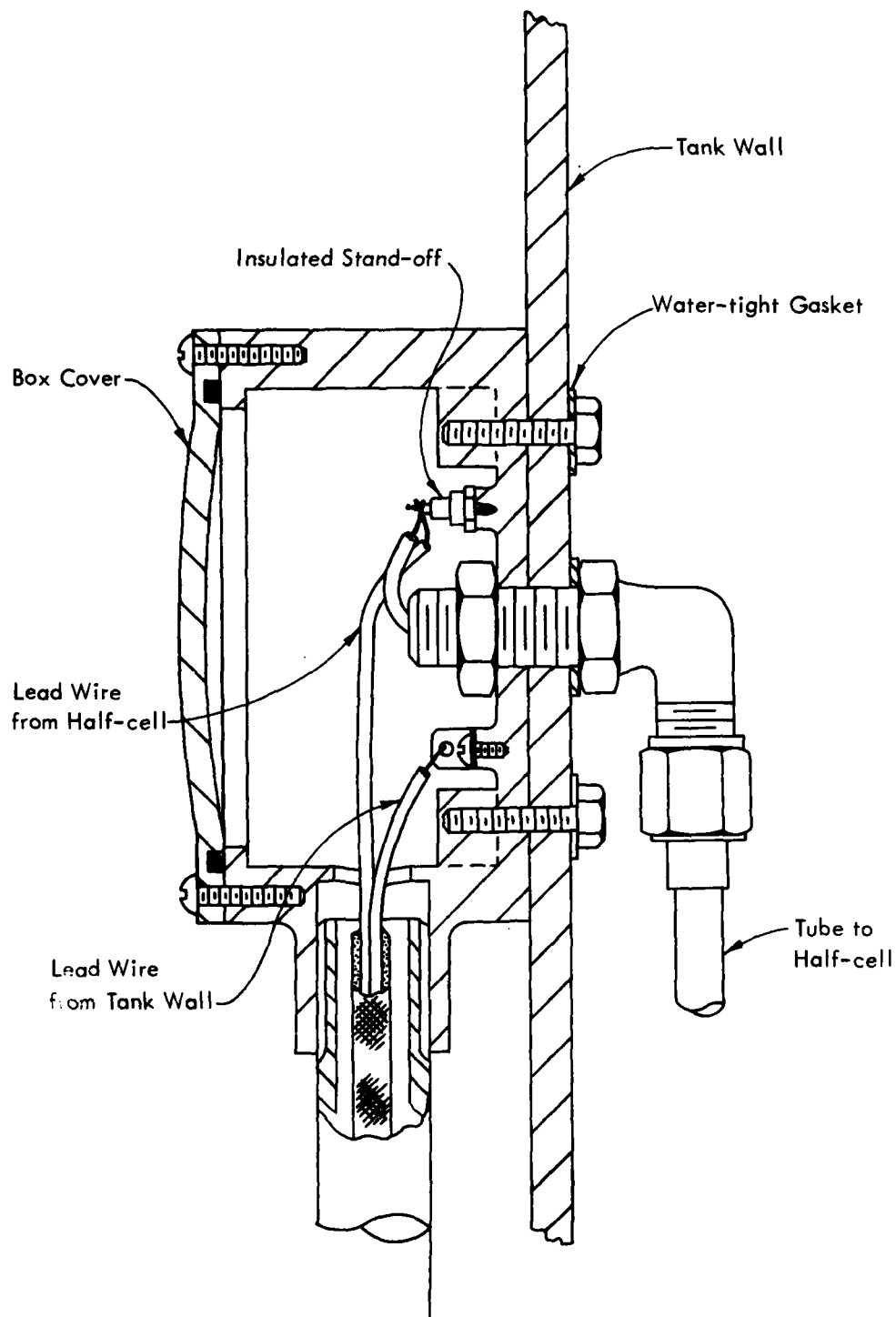


Figure 5. Junction box of surveillance system showing method of connecting half-cell.



Figure 6. Modified reference half-cell with additional ceramic jacket.



Figure 7. Reference half-cell with ceramic jacket cut away to expose silver/silver chloride electrode.

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