Managing galvanic corrosion

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Arthur H. Tuthill

Managing Galvanic Corrosion In Waters

Arthur H. Tuthill P.E.
Tuthill Associates, Inc.
PO Box 204
Blacksburg, Virginia 24060

Abstract

This paper summarizes 30 case history solutions to severe galvanic corrosion problems the author has encountered in heat exchangers, condensers, valves, pumps, steel and copper alloy welds, fasteners, coated hulls, ballast tanks, electrical connectors, propellers, and partially lined tanks. Guidelines are developed to assist engineers in managing galvanic corrosion problems they may encounter.

Galvanic Corrosion

When two different materials are welded, bolted or otherwise joined together in an electrolyte, the uncoupled corrosion rate of the least noble (anodic) is increased, and the uncoupled corrosion rate of the more noble (cathodic) is decreased. Inco's familiar galvanic series, Figure 1, shows which material of a couple in seawater is anodic and which is cathodic. Wesley and Brown's chapter in Uhlig's Corrosion Handbook provides an excellent description of the various reactions that can occur within a galvanic couple, ([1]). For the purpose of understanding the reactions occurring in these 30, cases the following provides sufficient background.

Anodic Reaction

The oxidation (corrosion) which occurs at the anode is represented thusly:

$$M^{O} \rightarrow M^{+} + e$$

Where M^{O} is a metal atom, Fe, Cu, Ni, Cr etc.
M^{+} is the metal ion in the electrolyte.
e is the electron from the metal atom.

Cathodic Reactions

In the vast majority of situations the cathodic reaction occurring in galvanic corrosion is oxygen reduction or hydrogen evolution or both.

The hydrogen evolution reaction is represented by $2H^{+} + 2e = H_2$
The reduction of oxygen occurs as follows

$$0_2 + 4H^{+} + 4e = 2H_20 \text{ (acid solutions)}$$
$$0_2 + 2H_20 + 4e = 40H^{-} \text{ (alkaline solutions)}$$

In oxygen containing waters at near neutral pH the oxygen reduction is of primary importance. The extend of corrsion is frequently controlled by the area of the cathode and the rate at which oxygen can reach its surface (mass transfer). However, under certain conditions the hydrogen evolution reaction can become important. This is primarily when the potential becomes cathodic such as in the case of CP being applied or very active metals such as aluminium or zinc being involved. Figure 2 shows the anodic and cathodic reactions

([1])Uhlig, H.H., "Corrosion Handbook", John Wiley and Sons, 1947.

and the electron flow from the anodic to the cathodic site (Ti tubes) for a copper alloy heat exchanger with titanium tubes. Superferritic and 6% austenitic stainless steel tubes would behave as titanium in this arrangement.

Uhlig states that the penetration (corrosion) follows this equation:

$P = P_0 (1 + B/A)$

Where P is the penetration (corrosion) of the anodic metal of area A coupled to the cathodic metal of area B.

P_0 is penetration of the anodic metal without coupling

From these basic reactions, it can be seen that the amount of dissolved oxygen available at the cathode, the surface area of the anode and the surface area of the cathode can have a major influence on the extent of galvanic corrosion that will occur. A small anodic surface will suffer much deeper corrosion than a large anodic surface. The lack of dissolved oxygen, as in deaerated solutions, will limit the reduction reaction to the formation of hydrogen which tends to be adsorbed on the cathodic surface thus reducing the cathodic area. A large cathodic area will result in more corrosion of the anodic metal than a small cathodic area. The engineer can reduce the cathodic area by painting the cathodic metal.

These are the principal factors on which solutions to the following 30 case histories were based.

Case History Solutions To Galvanic Corrosion Problems

Condensers And Heat Exchangers

1) Tube to Tubesheet Copper Alloy Systems: The common copper alloy tubing, admiralty, aluminum brass and copper nickel are cathodic to naval brass, muntz metal and aluminum bronze, the common copper alloy tube sheet alloys. The galvanic effect is not large but is in the desired direction - protection of the more critical component, the tubing. For copper nickel , C71500 tubing can be used with C70600 or C71500 tubesheets, with a beneficial or neutral galvanic effect. C70600 tubing should be used with C70600, naval brass, muntz metal or aluminum bronze tubesheets where the galvanic effect is neutral or beneficial. Were C70600 tubes to be used with C71500 tubesheets, the galvanic effect would tend to accelerate corrosion of the inlet end. This combination is generally avoided. The author's experience has been that the galvanic effect is small, does not significantly affect performance and is generally neglected for all these copper alloy combinations except for C70600 tubes in C71500 tubesheets which is best avoided.

2) Problem: Copper Nickel Plate Type Heat Exchangers: A naval flat plate type heat exchanger of C71500 was subject to inlet end erosion-corrosion due to the turbulence pattern at the inlet end. The inlet end of the plates eroded-corroded down to a knife edge.

Solution: Plates were redesigned in a C70600-C71500-C70600 roll bonded clad plate configuration. As the C70600 eroded-corroded, the C71500 was galvanically protected achieving the desired life.

3) Problem: Stainless steel and titanium tubes: copper alloy tubesheets: When copper alloy condensers were first retubed with 6% Mo and titanium tubes, it was thought the effective cathode area would extend only a few diameters down the tubes. Surprisingly severe corrosion of copper alloy tube sheets occurred. Several studies revealed that titanium and 6% Mo tubing were so easy to polarize that the whole

inside surface for as much as 40 feet from the inlet end was effective cathodic surface. This meant the cathode to anode ratio could approach a 1000 to 1, not 3 to 4 to 1 as originally supposed. ([2])

Figure 3 shows a half section of a copper alloy condenser or heat exchanger with titanium tubes. The differences in potentials for the various tubesheet materials coupled to titanium are shown. The potential difference between nickel copper alloy 400 and titanium is about 25% of the potential difference between naval brass or aluminum bronze and titanium suggesting nickel copper alloy 400 might perform better. However the effective cathodic area of the titanium is so large that it tends to overwhelmthe lower difference in potential. All tubesheet materials shown have suffered accelerated corrosion when coupled to titanium tubes.

Solutions: The principal solution to corrosion of copper alloy tube sheets in power plant condensers tubed with titanium, 6% Mo austentic or superferritic stainless steel has been installation of a well designed impressed current cathodic protection system in the waterbox. The potential and the potential distribution must be controlled so as to prevent hydryding of titanium or hydrogen embrittlement of superferritic tubing.

Iron anodes ar also used for this purpose. Many of the Middle East MSF unit reject sections have titanium tubes, CA 614 or 630 tubesheets with copper alloy waterboxes (sometimes 90/10CuNi or cast nickel aluminium bronze) with orin anodes to protect the copper alloys.

4) Problem: Waterboxes and Tubing: The early nuclear submarines were fitted with nickel copper alloy 400 waterboxes (the higher strength allowed a weight saving) and C71500 copper nickel tube sheets and tubes. The copper nickel tubing was anodic to and corroded preferentially to the nickel copper, alloy 400 waterboxes.

Solution: The cathodic surface area was reduced by solder wiping the nickel copper waterboxes with a 50:50 lead tin solder. Later the nickel copper waterboxes were redesigned and changed to C71500 accepting a slight weight penalty.

5) Problem: Waterboxes and tubing: Maintenance forces at one of the Office of Saline Water's desalination plants observed that there was considerable general corrosion of the bare steel waterboxes facing the copper nickel tube sheet and tubes. It was decided to epoxy coat the steel waterboxes. Figure 4 shows the deep pitting that occurred after the next 6 months operation. The coating failed locally at surface irregularities exposing the substrate steel to deep localized corrosion in saline water.

Since most of the coating was still intact all of the oxidation reaction, corrosion, had to occur in the very small area of steel exposed.

Solutions:

1 Epoxy coat the tubesheet and tube ends to reduce the cathodic area. This was the option chosen.
2 Install supplemental cathodic protection.
3 Increase anodic area by removing the coating from the waterbox allowing corrosion of the steel waterbox to continue over the whle surface area rather than at the localized areas where coating breakdown occurs. This is a last resort option as the steel corrosion products can, and have, of and failure to copper alloy tubing.

6) Problem: Waterbox waster plates: One shipowner outfitted his vessel with a complete C70600 copper nickel cooling water system and found that biofouling growth in the waterboxes was quite heavy despite the antifouling characteristics of copper nickel. Investigation revealed that the shipowner hadretained

([2]) Gehring, G.A. Jr., Kuester, C.K. and Maurer, J.R. "Effective Tube Length - A Consideration on Galvanic Corrosion of Marine Heat Exchanger Materials" NACE Corrosion/80 Paper No. 32, 1980 the steel waster plates which had been required in his former coated waterbox - aluminum brass tubed systems. The galvanic protection afforded the copper alloy waterbox negated its inherent antifouling characteristics allowing the waterboxes to foul.

Solution: Removal of the steel waster plates allowed C70600 to regain and retain its natural antifouling characteristics.

Valves

7) Problem: Stainless steel valves in copper alloy piping: The question of how stainless steel valves in a copper nickel piping system will perform frequently is asked. One answer has been supplied by the long term performance of alloy 20 (CN7M/Carpenter 20C63) valves installed in C70600 piping on a Gulf Coast cargo vessel.

Solution: The copper nickel piping adjacent to the stainless steel valves was inspected after several years in service. Slightly more pipe wall metal loss occurred adjacent to the stainless steel valve than several diameters from the alloy valve. The galvanic effect was spread over such a large area of pipe that no threat to the 20 year life of the piping system was indicated. Refer to Figure 5.

In a controlled test, May and Weldon, found the weight loss for C70600 pipe coupled to a CN7M valve was 3.2x as great as for C70600 pipe insulated from a CN7M valve in a 2 year controlled experiment. Flow rate was 3.7fps (1.1ms) (3)

8) Problem: Butterfly valves: The crude oil - ballast copper nickel piping system on a large tanker was fitted with a style of butterfly valves where the rubber seat was held in place with stainless steel keeper rings and did not cover the full carbon steel face of the valve. While this construction was appropriate for crude oil service, when the ballast tanks were filled with sea water the copper nickel, to steel area ratio was >20:1. Galvanic corrosion undermined the keeper rings, leading to failure and leakage.

Solution: The corroded area was machined out and rebuilt with alloy 625 filler metal which is cathodic to the copper nickel piping. After one year the rebuilt valves were in pristine condition and no increase in copper nickel piping corrosion could be detected.

Pumps

9) Problem: Saline water intake pumps: Stainless steel internals in vertical turbine intake pumps are quite resistant to the severe erosion - corrosion conditions when the pumps are operating but are vunerable to under deposit corrosion and microbial influenced corrosion when these pumps are placed on extended standby as is normal practice.

Solution: The inlet and diffuser sections, sometime the case, are made of austenitic nickel grey or dictule iron which provides sufficient galvanic protection to prevent corrosion of the stainless steel impeller and shaft while on standby.

In several cases where the inlet bell and diffuser section had been made of stainless steel depriving the impeller and shaft or protection, severe impeller and shaft corrosion occurred within the first year. Such

(3) May, T.P. and Weldon, B.A., "Copper-nickel alloys for service in seawater" 24th International Congress on Fouling and Marine Corrosion, Cannes, France June 8-13, 1964.

corrosion could have been prevented by replacing the inlet section with austenitic nickel iron. The users elected to use steel anodes in the stainless steel inlet section which were effective, but required periodic renewal.

Welds

10) Problem: Icebreaker hull welds: Welds on steel hulls and offshore oil structures are normally coated and/or cathodically protected. When coated and/or protected, little difference in the corrosion behavior of the weld metal and the base metal has been reported. Icebreakers however, abrade off coatings and strip off anodes, as they move through the ice. In the early 1960's severe weld corrosion of icebreaker hulls was reported. Investigation by International Nickel's marine corrosion laboratory indicated the matching composition filler metal normally used was anodic to and corroded preferentially to the hull plate, Figure 6.

Solution: The weld metal was changed to one contining 1% Ni insuring that the weld metal would be cathodic to the hull.

11) Problem: Rudder welds: In the 1980's the author encountered weld metal corrosion of a large steel rudder where the coating and cathodic protection were ineffective apparently due to highly turbulent conditions around the rudder.

Solution: In this case the shipowner elected to use an even more cathodic filler metal, alloy 625, to provide greater insurance of good performance under the highly turbulent conditions surrounding this particular rudder.

12) Problem: Filler metal for copper nickel: Standard practice is designed to avoid most galvanic corrosion problems. The higher nickel content alloy, 70-30 copper nickel, C71500 is welded with a near matching composition filler metal which has a slightly higher alloy content making it cathodic to the C71500 base metal. Monel filler metal which is strongly cathodic to C71500 is also used as a filler metal for C71500 and for copper nickel to steel welds.

The lower nickel content alloy, 90-10 copper nickel, C70600, is welded with C71500 filler metal which is quite cathodic to the lower nickel content alloy. Most welding rod suppliers do not offer a matching composition filler metal for the leaner C70600 alloy fearing it might inadvertently be used on C71500 with catastrophic results.

13) Problem: Filler metal for aluminum bronze: C63000 and C954000, 8% aluminum bronzes, are welded with a higher aluminum content to weld metal to prevent stress corrosion cracking. The higher aluminum content weld metal in slightly anodic to the base metal. Experience has shown the slightly anodic weld metal performs well in fabricated waterboxes, pumps and column pipes. However, some fabricators advocate using a matching composition filler metal for the final bead. While it is desirable to have the weld metal cathodic to the base metal, it is not always possible to do so as in the case of aluminium bronze. Experience is the best guide.

14) Problem: Filler metal for other copper alloys: Silicon and phosphor bronze alloys are generally welded with a matching composition filler metal. Preferential corrosion of such welds, when it occurs, is an indication that a more noble filler metal, such as copper nickel or nickel copper should be used.

15) Problem: Filler metal for stainless steels: Stainless steels do not exhibit the tendency towards galvanic corrosion of the weld metal found in steels and copper alloys. Stainless steels can be sensitized to intergrannular corrosion (IGA) if the older 0.07 or 0.08% carbon max. grades are selected for welded fabrication in lieu of the more common 0.03% carbon max. grades. The 4 1/2% and 6% Mo grades are fabricated using a higher Mo content filler metal to avoid weld metal corrosion that can occur with a matching

composition filler metal. The reduction in corrosion that occurs when matching composition filler metals are used in welding the higher molybdenum filler metals is due to segregation of molybdenum in the cast weld metal structure. Solution annealing (SA) at 2150F (C) will homogenize molybdenum. When SA is impractical a higher molybdenum content filler metals such as 625, C276 or C22 are used. Neither IGA or molybdenum segregation are due to galvanic factors, however.

Fasteners

16) Problem: Stainless steel fasteners were used to secure the aluminum awning to the store front of a building in a coastal city. The aluminum bolt holes were enlarged by galvanic corrosion allowing the awning to drop, Figure 7.

Solution: Pack the bolt holes with a lubricant that will adhere to and displace moisture from metallic surfaces at assembly. Inspect and repack as necessary. An adherent lubricant insulates the dissimilar metals, not completely, but sufficiently to markedly reduce the aluminum hole enlargement. Most lubricants are not adherent and may promote rather than mitigate such galvanic corrosion.

17) Problem: The steel stuffing box bolts in the bilge of a copper nickel hulled work boat were covered by sea water and failed by galvanic corrosion allowing water to enter nearly sinking the vessel.

Solution: The steel bolts were replaced with nickel copper alloy 400 bolts which are cathodic to copper nickel as originally specified.

18) Problem: Stainless steel fasteners in FRP hulls below the waterline fail by crevice corrosion for lack of the galvanic protection a steel or aluminum hull would have provide.

Solutions: 1) Enbed the fasteners more securely in resin so sea water will not wick into the fastener recess.
2) Use nickel copper alloy 400 bolts.

19) Problem: Brass screws holding a steel port hole fitting on a steel hulled boat failed by dezincification in heavy seas flooding the head and nearly sinking the boat before the port hole opening could be closed.

Solution: Use nickel copper alloy 400 screws.

20) Problem: Nickel copper alloy K500 and other high strength fasteners have failed in cathodically protected strucutres in sea water from the hydrogen released by the cathodic protection system on cathodic surfaces.

Solution: Avoid fasteners with > 100,000 psi tensile strength in cathodically protected structures. Use nickel copper alloy 400 fasteners.

The following guidelines are helpful in selecting fasteners

1 Select fastener material that is cathodic to all other metals in the assembly.

2 Avoid use of fasteners with >100,000 psi tensile strength in structures that are, or may be, cathodically protected at sometime in their useful life.

3 Avoid brass screws that are subject to dezincification. Although steel will galvanically protect copper and bronze, steel is not alway effective in preventing dezincification of high zinc brasses.

4 Good performance of stainless steel fastener materials is dependent upon galvanic coupling with steel or similar anodic substrates to prevent crevice corrosion.

5 In the atmospheres or low conductivity fluids such as fresh water where galvanic effects are limited to the immediate area of the junction between the fastener and substrate, failure by hole enlargement can be just as serious as failure of the bolt itself.

Hull Related Cases

21) Problem: Deep corrosion occurred in the steel hull adjacent to the weld joining the nickel copper alloy valve body to the hull in the bell shaped inlet of an older type submarine hull cooling water intake, Figure 8. The hull cathodic protection system was not effective in preventing localized corrosion in this deep recess and could not easily be modified to do so.

Solution: The coating was removed from the bell mouth by sandblasting, enlarging the anodic area and spreading the corrosion over a larger area thus reducing the depth of attack.

22) Problem: A nickel copper alloy pipe passed through a well coated steel ballast tank on an older type submarine. Deep corrosion of the steel bulkhead occurred adjacent to the nickel copper pipe to steel weld where the coating tended to fail over the rough pipe to bulkhead weld. Rewelding and recoating of the repaired area only moved the problem to the area just beyond the repair weld, Figure 9.

Solution: Coating the nickel copper alloy pipe reduced the cathodic area and extended the yearly inspection for repairs to a more acceptable 5 plus, year period. This is a classic case of coating the more durable cathodic material to reduce galvanic corrosion.

Note: The 1981 Edition of the Naval Technical Manual "Preservation of Ships" Chapter 631 Section 7.107 now requires "Monel, copper nickel and other alloy pipes to be coated so as to minimize galvanic corrosion of steel at alloy pipe to steel bulkhead welds."

23) Problem: Electrical connectors: Electrical connectors are required to supply power to the winches and other equipment external to the hull and under the shroud of submarines. This equipment operates in sea water. Type 316 through hull connectors are standard for this service. Each is welded to the hull to maintain hull tightness and integrity. The steel hull and its cathodic protection system prevent crevice corrosion of the type 316 electrical connectors that would occur in the absence of protection.

24) Problem: Stainless steel propellers: Stainless steel is subject to crevice and under biofouling corrosion in coastal waters. Type CF3 propellers have, nevertheless, been used successfully since 1952 and are standard for coastal tugboats, towboats and workboats in the U.S. Blades are straightened and weld repaired routinely. Stainless steel is quite resistant to velocity and turbulence while these work boats are in operation. The steel hull and its cathodic protection system provide sufficient galvanic protection to prevent crevice corrosion of the stainless steel propellers while these craft are in port and idle. The low carbon permits weld repair without sensitization.

Partial Linings

Partial stainless steel linings are installed in steel tanks and vessels by weld overlay, metal spray or sheet lining. The author has encountered galvanic corrosion at the termination of the lining and at piping that passes through the lined area. The nature of the electrolyte modifies the galvanic effect.

Galvanic corrosion has occurred at

I The termination of lining above the liquid in the vapor zone.

II The termination of lining below the liquid level.

III Carbon steel piping passing through the stainless steel lined section of tank. Refer to Figure 10 and sections A, B & C.

25) Problem: I Vapor Zone: Termination of lining above the liquid in the vapor zone. Galvanic corrosion results in a groove in the steel adjacent to the alloy termination weld, Figure 10 Section A. The anode to cathode area is approximately 1:1. The groove deepens slowly with time.

Solution: Yearly monitoring and rewelding when the depth of groove warrants is the normal remedial measure.

26) Problem: III Liquid zone: Carbon steel pipe penetrating the lined portion of the tank wall.

Galvanic corrosion leads to corrosion of the steel pipe at the junction with the alloy lining. Figure 10 Section B.

Solutions: 1) Replace with stainless steel piping.
2) Coat the stainless steel liner to reduce the cathodic surface and minimize corrosion of the steel piping.

27) Problem: II A.1 Liquid zone: Termination of lining below the liquid level in a poorly conducting electrolyte such as fresh water. Tank uncoated below lining.

A deep groove forms in the steel just below the alloy to steel weld, Figure 10 Section C-A.

Solution: Yearly rewelding of the groove is often necessary. The groove reforms just below the rewelded area if alloy filler metal is used; in the rewelded area if carbon steel filler metal is used.

28) Problem: II A.2 Liquid zone: Termination of lining below liquid level in alkaline paper mill liquor.
Tank wall coated below partial lining.

Deep localized corrosion can occur in areas where the coating may be scratched, damaged or where localized coating failure occurs over weld metal or surface irregularities. Through wall corrosion and leakage can be anticipated at breaks in the coating within a year or so. Figure 10 Section C-B.

Solution: 1) Supplemental cathodic protection in the lower portion of the tank will prevent corrosion at breaks in the coating.
2) Coat the cathodic surface, the stainless steel liner, to reduce the cathodic surface and minimize corrosion at breaks in the coating.

29) Problem: II A3 Liquid zone: Termination of lining below the liquid level in an alkaline paper mill liquor, a highly conductive electrolyte. Tank uncoated below the partial lining.

Metal loss is spread out over a large area of the carbon steel. It is difficult to measure the slightly greater metal loss adjacent to the lining, Figure 10 Section C-C.

Solution: Yearly monitoring is normally all that is required.

Carbon - Graphite

30) Problem: Graphite or carbon filled gaskets and packing: Severe pitting corrosion of stainless steel and copper alloy valve stems, pumps shafts and flange faces in contact with graphite/carbon filled non metallic

packing, gaskets and lubricants.

Most black or dark packings, gaskets and lubricants contain graphite/carbon which is quite noble (cathodic) to copper alloys and stainless steels. In saline waters severe pitting corrosion has occurred where such materials come in contact with copper alloy or stainless steel valve stems, pump shafts or flange faces.

Solution: Ban graphite filled non metallic packing and gaskets in brackish and saline waters. Only occasional problems have been reported in fresh waters.

Summary

1) When two dissimilar metals are in contact, corrosion of one will be increased and corrosion of the other will be retarded. Galvanic corrosion can be successfully managed and made to works towards, rather than against, durability of the assembly by understanding and utilizing the principles that govern galvanic corrosion.

2) Increasing the anodic area (by removing any coating) will allow the corrosion to be spread over a larger area below the liquid level in a conductive fluid. Increasing the anodic area in a poorly conductive fluid or above the liquid level is ineffective.

3) Painting the cathodic area will reduce the effective cathodic area and reduce corrosion of the anode in a conductive fluid.

4) Selecting cathodic materials, often highly cathodic materials, for fasteners, for weld filler metals and for the critical component of an assembly such as a pump or valve will take advantage of the galvanic effect, making the assembly more durable.

5) The cathodic member of a couple can initiate damaging corrosion of bolt holes, tubesheets and coated anodic surfaces.

6) The cathodic member can be damaged by the hyrodgen released on cathodic surfaces in cathodically protected structures and in some galvanic couples.

7) Avoid use of graphite filled packing and gaskets in brackish and saline waters.

Acknowledgement

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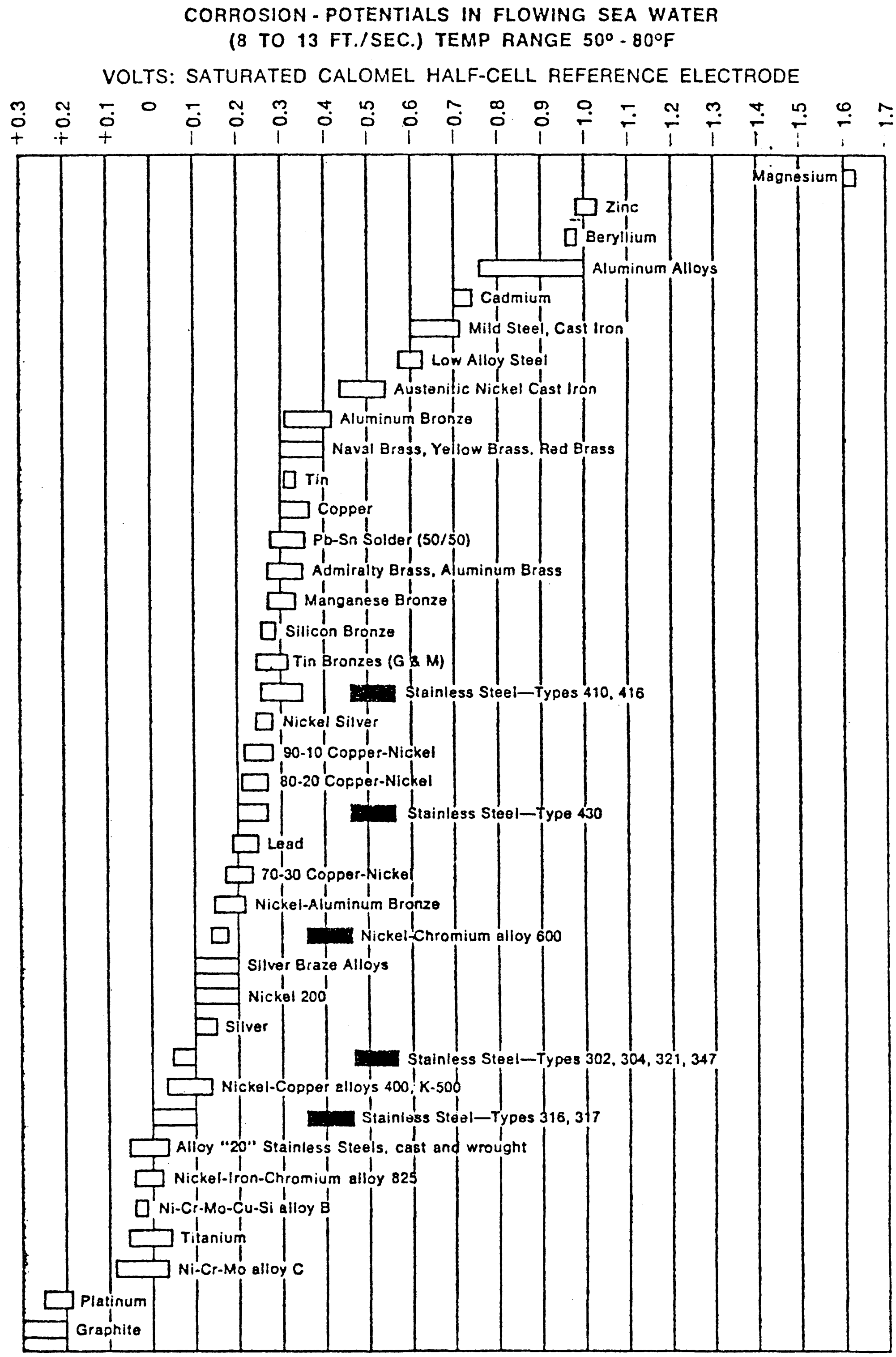
3. May, T.P. and Weldon, B.A., "Copper-nickel alloys for service in seawater" 24th International Congress on Fouling and Marine Corrosion, Cannes, France June 8-13, 1964



Alloys are listed in the order of the potential they exhibit in flowing sea water. Certain alloys indicated by the symbol: ▇▇ in low-velocity of poorly aerated water, and at shielded areas, may become active and exhibit a potential near -0.5 volts

Figure 1 Galvanic Series - Flowing Seawater (INCO)

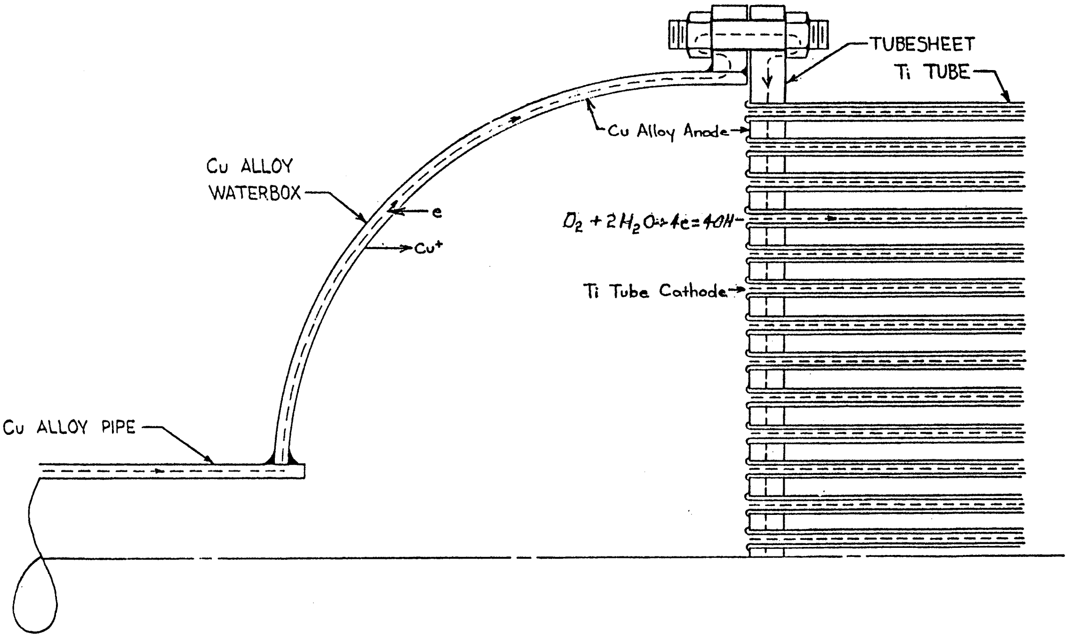


Figure 2 Upper half of waterbox and inlet end of a condenser or heat exchanger

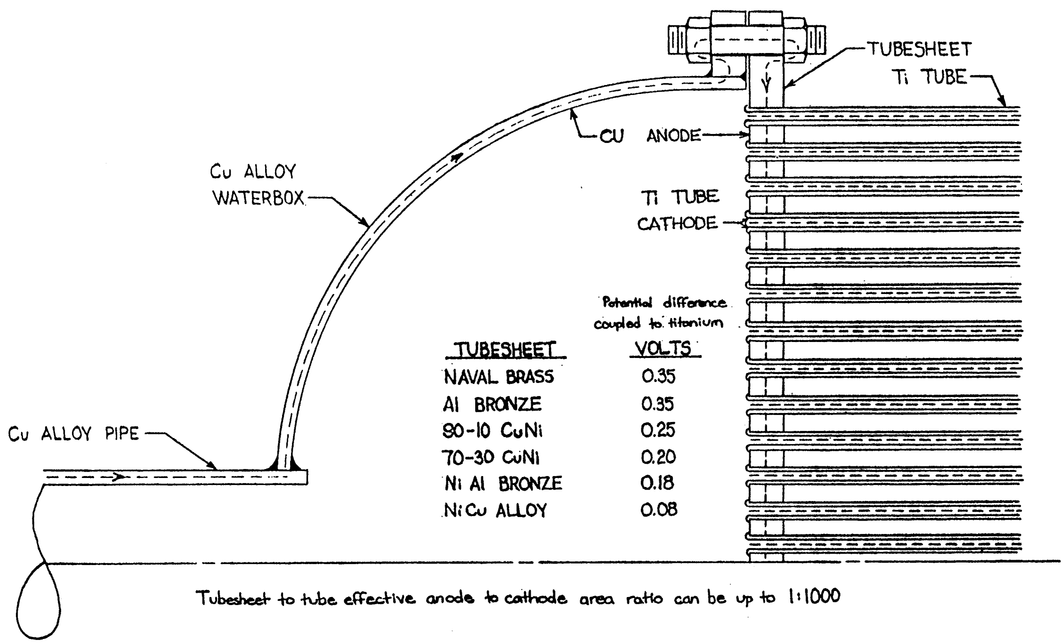


Figure 3 Upper half of waterbox and inlet end of a titanium tubed copper alloy condenser of heat exchanger. The adverse area ratio overwhelms the differences in potential.

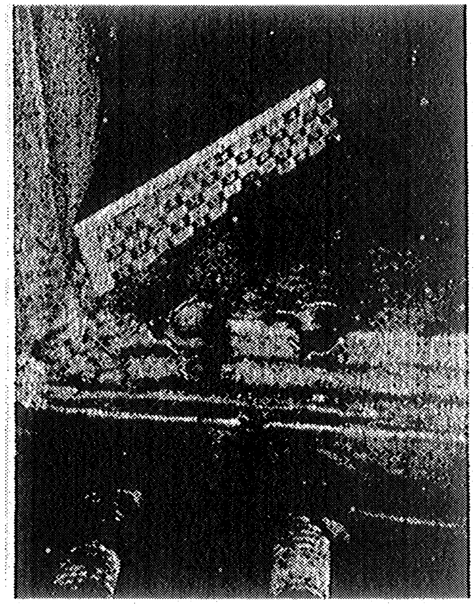


Figure 4 Deep pitting in coated steel waterbox in a desalintion heat exchanger with C70600 tube sheet and tubes - 6 months

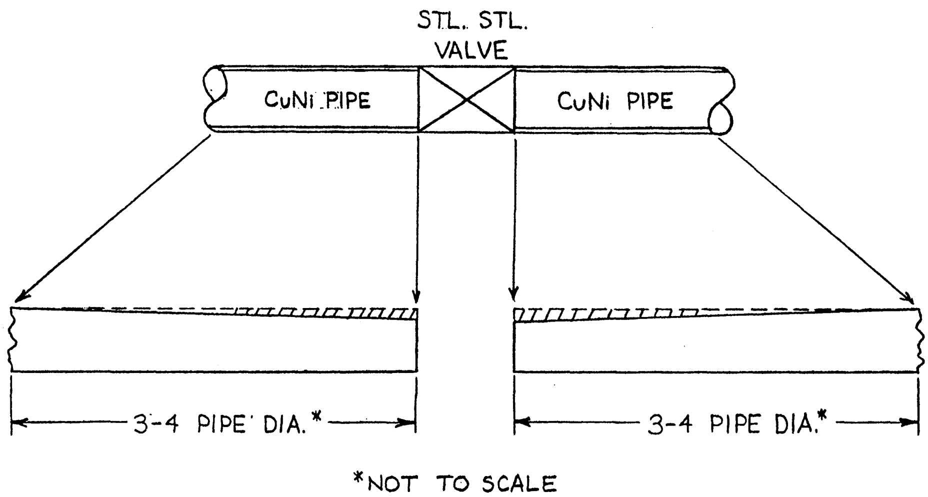


Figure 5 Metal loss patgtern in CuNi pipe adjacent to SH. SH. valve (seawater)

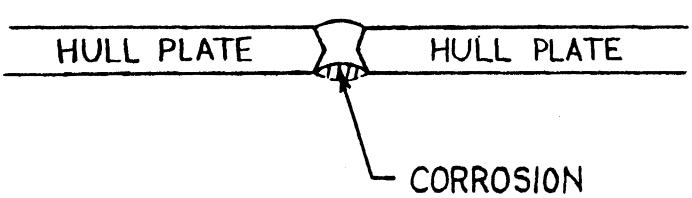


Figure 6 Corrosion of hull plate weld with CP (seawater)

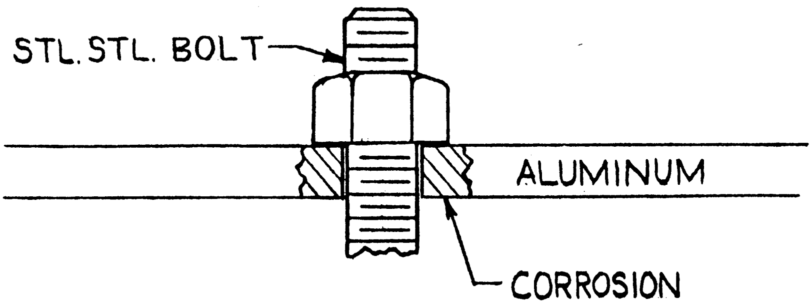


Figure 7 Corrosion enlarges aluminum bolt hole
(Marine atmosphere)

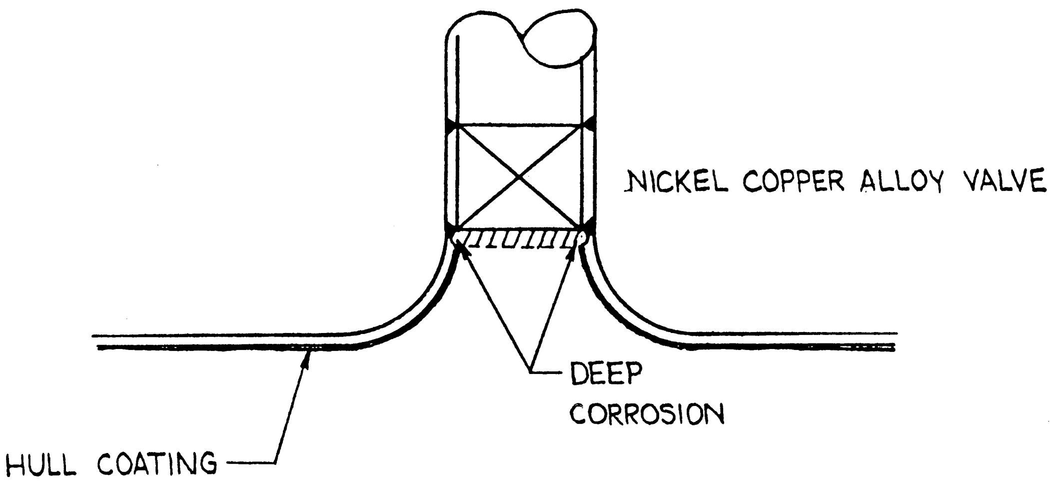


Figure 8 Deep corrosion in hull adjacent to nickel copper alloy to steel hull weld (seawater)

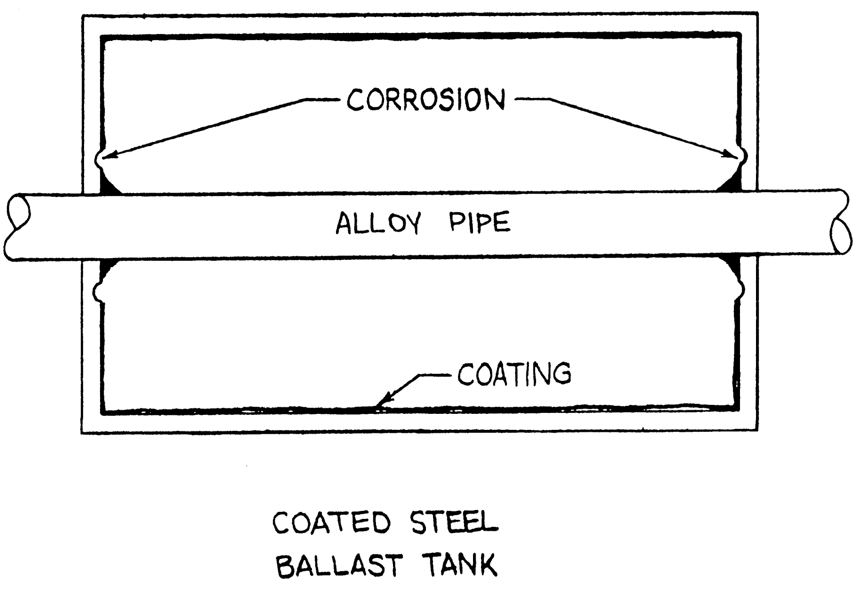


Figure 9 Corrosion of steel bulkhead adjacent to alloy pipe to bulkhead weld

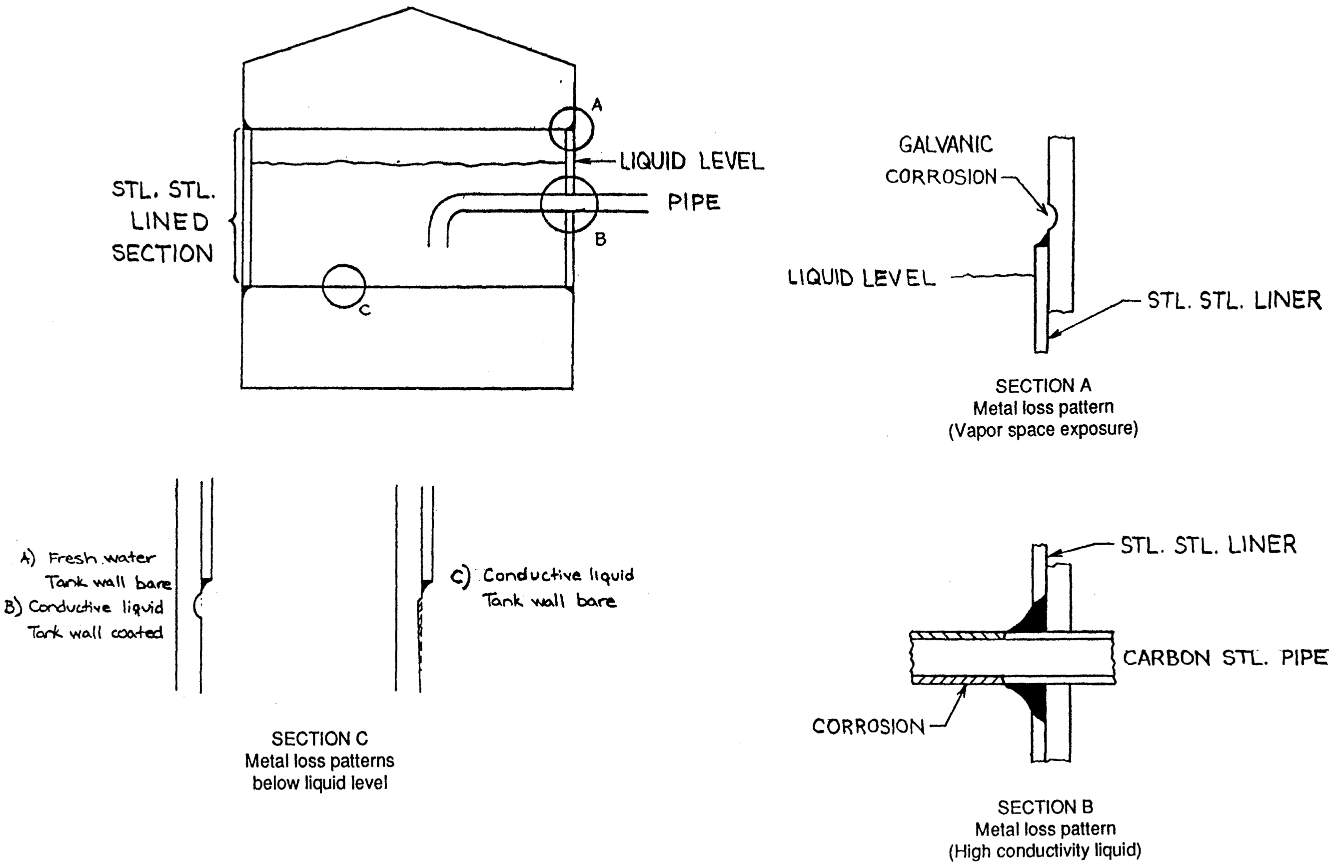


Figure 10 General arrangement of a tank with a partial SH. SH. liner in the area of the liquid level

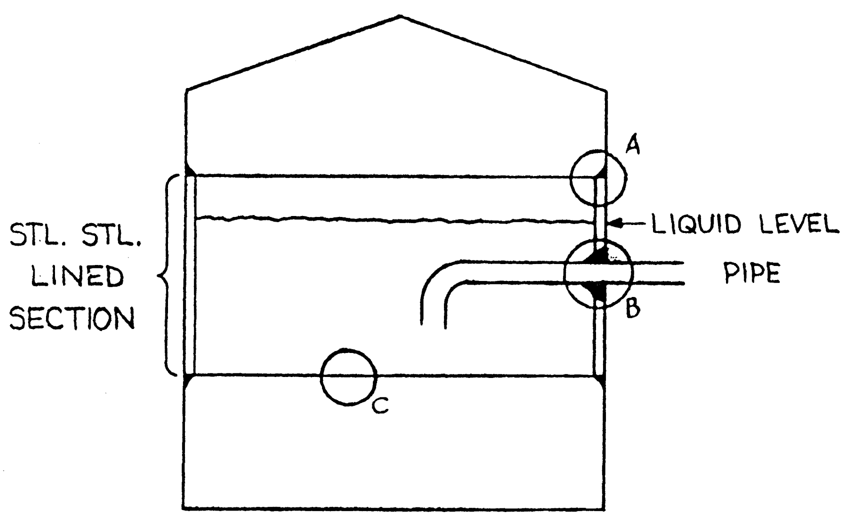
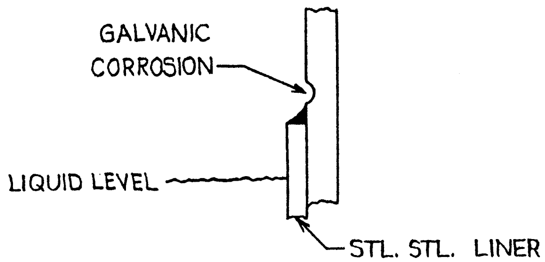
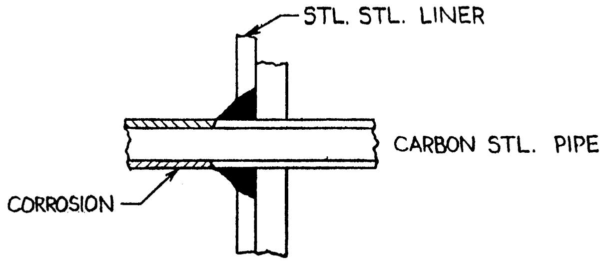


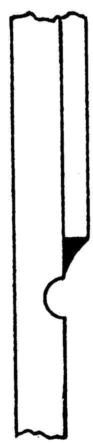
Figure 10 General arrangement of tank with a partial stainless steel liner in the area of the liquid level



SECTION A OF FIG. 10
Metal loss pattern above liquid level
(Vapor space exposure)

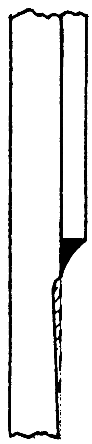


SECTION B OF FIG. 10
Metal loss pattern - carbon steel pipe passing
through stainles steel liner below liquid level
(High conductivity liquid)



A) Fresh water
Tank wall bare

B) Conductive liquid
Tank wall coated



Conductive liquid
Tank wall bare

SECTION C OF FIG. 10
Metal loss patterns
below liquid level

The Nickel Development Institute is an international nonprofit organization serving the needs of people interested in the application of nickel and nickel-containing materials.

North America

Nickel Development Institute
214 King Street West - Suite 510
Toronto, Ontario
Canada M5H 3S6
Telephone 1 416 591 7999
Fax 1 416 591 7987

Europe

Nickel Development Institute
42 Weymouth Street
London, England W1N 3LQ
Telephone 44 171 493 7999
Fax 44 171 493 1555

Nickel Development Institute
European Technical Information Centre
The Holloway, Alvechurch
Birmingham, England B48 7QB
Telephone 44 152 758 4777
Fax 44 152 758 5562

Japan

Nickel Development Institute
11-3, 5-chome, Shimbashi
Minato-ku, Tokyo, Japan
Telephone 81 3 3436 7953
Fax 81 3 3436 7734

Central & South America

Nickel Development Institute
c/o Instituto de Metais Não Ferrosos
Av. 9 de Julho, 4015, 01407-100
São Paulo-SP, Brasil
Telephone 55 11 887 2033
Fax 55 11 885 8124

India

Indian Nickel Development Institute
c/o India Lead Zinc Information Centre
Jawahar Dhatu Bhawan
39 Tughlaqabad Institutional Area
Mehrauli-Badarpur Road
New Delhi 110 062, India
Telephone 91 11 698 0360
Fax 91 11 698 9522

Australasia

Nickel Development Institute
P.O. Box 28, Blackburn South
Victoria 3130, Australia
Telephone 613 9878 7558
Mobile 61 18 346 808
Fax 613 9894 3403

South Korea

Nickel Development Institute
Olympia Building, Room 811
196-7 Jamsilbon-Dong, Songpa-Ku
Seoul 138 229, South Korea
Telephone 82 2 419 6465
Fax 82 2 419 2088

Members of NiDI

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