

**PUBLIC WORKS TECHNICAL BULLETIN 420-49-37**  
**15 June 2001**

**CATHODIC PROTECTION**  
**ANODE SELECTION**

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DEPARTMENT OF THE ARMY  
U.S. Army Corps of Engineers  
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Washington, DC 20314-1000

CEMP-R

Public Works Technical Bulletin  
No. 420-49-37

15 June 2001

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UTILITIES

CATHODIC PROTECTION ANODE SELECTION

1. Purpose. The purpose of this Public Works Technical Bulletin (PWTB) is to transmit current information on selection criteria for both Galvanic and Impressed Current Anodes that may be installed with new or existing Cathodic Protection Systems.
2. Applicability. This PWTB applies to all U.S. Army Public Works public works activities.
3. References.
  - a. AR 420-49-02, Facilities Engineering Utility Services, 28 May 1997.
  - b. Code of Federal Regulation, CFR Title 40: Protection of Environment, Chapter 1, parts 280-281.
4. Discussion.
  - a. This PWTB is intended to provide guidance in selecting a particular type of anode material when designing new cathodic protection systems as well as when replacing (retrofitting) existing anode systems in existing systems. This guidance is based on review of Course Material developed by the Construction Engineering Research Laboratories (CERL) for the Department of Public Works (DPW) entitled "Cathodic Protection Anodes Selection for Sacrificial and Impressed Current CP Systems".
  - b. Cathodic protection is an electrical method of mitigating corrosion on structures that are exposed to electrolytes such as soils and waters. Corrosion control is achieved by artificially causing direct current to flow from auxiliary anodes, through the electrolyte (soil or water), and onto the structure to be protected. The attached document titled provides detailed information on anodes, their selection and cathodic protection technology.

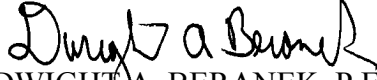
PWTB 420-49-37

15 June 2001

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**SELECTION CRITERIA FOR ANODE  
MATERIALS  
FOR USE IN CATHODIC  
PROTECTION SYSTEMS  
USED ON BURIED AND SUBMERGED  
METALLIC STRUCTURES**

**GUIDANCE**

# **SELECTION CRITERIA FOR ANODE MATERIALS FOR USE IN CATHODIC PROTECTION SYSTEMS USED ON BURIED AND SUBMERGED METALLIC STRUCTURES**

## **1. Introduction.**

a. Background. Cathodic protection is an electrical method of mitigating corrosion on structures that are exposed to electrolytes such as soils and waters. Corrosion control is achieved by artificially causing direct current to flow from auxiliary anodes, through the electrolyte (soil or water), and onto the structure to be protected. Corrosion of the structure is completely eliminated when the open-circuit potentials of the cathodic sites are polarized to the open-circuit potentials of the anodic sites. The entire structure becomes cathodic relative to the installed auxiliary anodes. There are two types of Cathodic Protection Systems. The first type makes use of metals which are more reactive than the metal to be protected from corrosion.

b. Need for Effective Cathodic Protection.\_The Army must meet U.S. Environmental Protection Agency (USEPA) requirements for corrosion control on underground storage tanks (USTs) and their associated piping in accordance with 40 CFR, parts 280-281. Less than ten percent (10%) of Army USTs tested during an FY93-94 USACPW survey were in compliance with the USEPA requirements for CP on buried metallic USTs. The Army must also meet the CP requirements of the U.S. Department of Transportation (USDOT) requirements for corrosion control on pipelines conveying natural and other flammable gases and hazardous (flammable) liquids per 49 CFR, parts 190 through 195.\_These requirements require effective cathodic protection be provided and maintained in continuous operation throughout the operating life of the piping system. Army guidance (ETL 1110-3-440), in addition to requiring compliance with the USDOT regulations, requires effective cathodic protection on elevated water storage tanks.

c. One of the more common problems which results in either ineffective or failed cathodic protection is failure of some or all of the anode element(s) which are arguably the single most important component of the CP system. This is most often do to incorrect selection of the appropriate material or incorrect operation of them after installation.

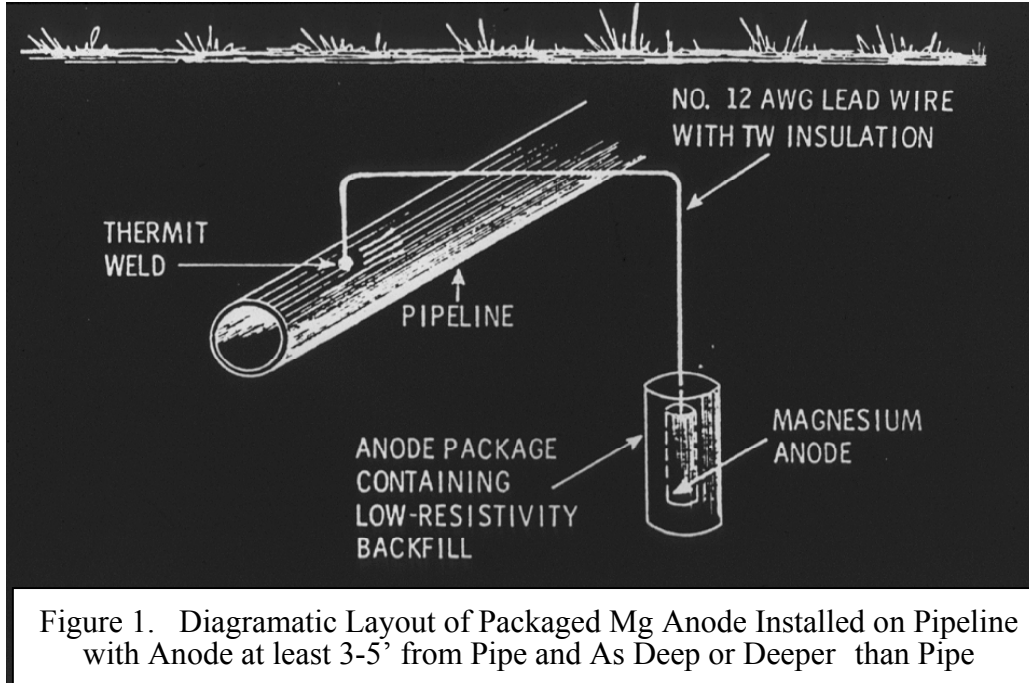
d. The Army design manual and ETLs describe specific examples of CP design and in some cases show both type of CP system design. These design manuals and ETLs, as a general rule, do not give guidance as to what type of anode to select for either galvanic or impressed current CP systems.

e. The need for this PWTB was identified as a result of comments received at the FY97 Tri-Service Corrosion Course conducted by CERL at which attendees clearly identified a need for this specific technical bulletin.

## **2. Sacrificial Anode Type Cathodic Protection**

a. Sacrificial anode type cathodic protection systems provide cathodic current by galvanic corrosion. The current is generated by metallicity connecting the structure to be protected to a metal/alloy that is electrochemically more active than the material to be protected. (Both the structure and the anode must be in contact with the electrolyte.) Current discharges from the expendable anode, to the electrolyte, and onto the structure to be protected.

b. The basic components of a single, sacrificial anode type cathodic protection installation are the structure to be protected, the anode (with or without a special backfill), and an insulated lead wire connecting the structure to the anode.



c. Advantages of Galvanic Anode System

- (1) No external power required
- (2) No regulation required
- (3) Easy to install
- (4) Not source of stray DC interference currents
- (5) Anodes can be readily added
- (6) Minimum of Maintenance
- (7) Uniform distribution of current
- (8) Installation can be inexpensive\*
- (9) Minimum right-of-way/easement costs
- (10) Efficient use of protective current
- (11) Low Cost per Unit Installed

d. Limitations of Galvanic Anode System

- (1) Limited driving potential
- (2) Fixed driving potential
- (3) Lower/limited current output
- (4) Installation can be expensive\*\*
- (5) Poorly-coated structures require many anodes
- (6) High Cost per Ampere-Year of current generated
- (7) Can be ineffective in high-resistivity environments

\*Installation of anodes at time of construction

\*\*Installation of anodes after construction

3. Types of Galvanic Anode Materials

a. Aluminum Alloys.

(1) Aluminum Alloy anodes are limited to use in seawater or very brackish water use (must have more than 1000 ppm chloride ion concentration for Indium alloyed material and 10,000 ppm Cl<sup>-</sup> for Mercury alloyed material)

(2) Typical Alloy Content:

**Table 1**

<b>Element</b>	<b>Mercury Based Alloys Percent (by weight)</b>	<b>Indium Based Alloys Percent (by weight)</b>
<b>Zinc</b>	0.35% - 0.50%	2.8% - 3.5%
Silicon	0.14% - 0.21%	0.08% to 0.0.20%
Mercury	0.035 - .048%	n/a
Indium	n/a	0.01% – 0.02%
Aluminum	Remainder	Remainder

(3) Aluminum Anode operate at approximately 95% efficiency yielding approximately 1250 amp-hrs-lb or a consumption rate of approximately 6.8 lbs./amps-yr in seawater applications only. This efficiency may drop in half or more in brackish waters.

- (4) Low driving potential (e.g. 0.250 volts to protected steel)
- (5) Lowest Galvanic Anode Cost (\$ per Ampere-Year of current generated)



(6) Are never used with select backfill and thus are installed as bare ingots. They typically are mounted to the structure they are intended to protect via their integrally cast galvanized iron core straps, pipes or rods.

(7) Output capacities are usually obtained from standard tables providing current output in amperes assuming a seawater environment with a resistivity of 25 ohm-cm or by using H. B. Dwight's equation to calculate the resistance of a single anode in seawater.

<b>Equation 1</b>	$R \approx \frac{.00521 \times \rho}{L} \times \left( \frac{\ln 8L}{d} - 1 \right)$
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where:

- R = Anode to Electrolyte Resistance
- $\rho$  = the electrolyte resistivity in ohm-cm
- L = the anode length in feet
- ln = natural or naperian logarithm
- d = the anode actual diameter in feet or equation below

(8) Ohm's law is then used to calculate the current output of the anode presuming a net driving potential of 0.25 volts.

<b>Equation 2</b>	$I \equiv \frac{E}{R}$
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where:

- I = Anode Current Output in Amperes
- E = Assumed Net Driving Potential (for Aluminum vs Steel, usually 0.250 Volts)
- R = Calculated Resistance in Ohms

(9) If the anode has a rectangular cross section, the equivalent diameter is determined by the equation:

<b>Equation 3</b>	$d \approx \sqrt{\frac{4 \times w \times h}{\pi}}$
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where:

- w = the anode cross section width
- h = the anode cross section height
- $\pi$  = 3.14159

#### 4. Magnesium Alloys

- a. Highest operating Voltage of all common Galvanic Anodes but has the lowest efficiency and highest cost per ampere year of current flow.
- b. Typically used in soils and waters with resistivities higher than 1500 ohm-cm.
- c. Electrochemical properties of Magnesium Anodes
  - (1) Ampere Hour/Pound Consumed Theoretical .....1000
  - (2) Current Efficiency ..... 50%
  - (3) Ampere Hours/Pound Consumed Practical .....500
  - (4) Pounds Consumed per Ampere-Year of Output .....17
  - (5) Solution Potential in gypsum backfill with respect to a Cu/CuSo4
    - AZ-63 Alloy (grades A & B only) -1.55 Volts
    - AZ-63 Alloy (grade C only) -1.2 to 1.5 Volts
    - Mg-Mn "High Potential" Alloy -1.73 Volts
  - (6) Alloy Contents

**Table 2**

<b>Alloy Element Content (% of total weight)</b>	<b>High Potential</b>	<b>AZ-63 Grade "B" (H-1 Alloy)</b>	<b>AZ-63 Grade "B" (H-1 Alloy)</b>	<b>AZ-63 Grade "C" (H-1 Alloy)</b>
Aluminum	0.010 max.	5.3 – 6.7	5.3 – 6.7	5.0 – 7.0
Manganese	0.50 – 1.30	0.15 min.	0.15 min.	0.15 min.
Zinc	0.05 max.	2.5 – 3.5	2.5 – 3.5	2.0 – 4.0
Silicon	0.05 max.	0.10 max.	0.30 max.	0.30 max.
Copper	0.02 max.	0.02 max.	0.05 max.	0.10 max.
Nickel	0.001 max.	0.002 max.	0.003 max.	0.003 max.
Iron	0.03 max.	0.003 max.	0.003 max.	0.003 max.
Other (Each Element)	0.05 max.	0.05 max.	0.05 max.	0.05 max.
Other (Total of other Elements Combined)	0.30 max.	0.30 max.	0.30 max.	0.30 max.
Magnesium	Remainder	Remainder	Remainder	Remainder

5. Anode life

- a. Anode life is primarily governed primarily by weight, current output, and efficiency.
- b. The heavier the anode, the longer the life.
- c. The higher the current, the shorter the life.

d. The higher the efficiency, the longer the life.

e. The life of a galvanic anode can be calculated from the following general formula:

$$\text{Equation 4} \quad L \approx \left( \frac{W}{I \times Cr} \right) \times Uf$$

where:

L = anode life in years

W = anode weight in pounds

I = anode current output in amperes

Cr = anode practical consumption rate equals the theoretical rate x efficiency

Uf = anode utilization factor (usually assumed to be 85% of the calculated total life).

(1) The practical consumption rate for high potential and grade a & b az-63 magnesium anodes is usually assumed to be 17 pounds/ampere-year of operation. This assumes that the magnesium has an operating efficiency of 50%.

(2) Current output of any anode is fundamentally controlled by the soil resistivity, the anode shape and the net driving potential between the anode and the structure:

(A) The lower the resistivity, the higher the current output

(B) The longer the length of the anode, the lower the resistance

(C) Increasing anode diameter does not reduce the resistance very much but it does significantly increase the anode weight and therefore increasing the diameter adds predominately useful life to the anode

(D) The higher the net driving potential between the anode and cathode, the higher the current.

(3) Magnesium anode ingot sizes and dimensions table (information courtesy of Stuart Steel Protection Corporation, Bound Brook, NJ):

**Table 3**

Anode metal weight (pounds)	Anode cross section shape	Galvanized steel core type	Diameter or trapezoid base x top x height (inches)	Length
1	Round	Perf. Flat strap	1.63	8.25
3	Round	Perf. Flat strap	2.75	9
5	Round	Perf. Flat strap	3.38	10
9	Round	Perf. Flat strap	4.00	13.75
17	Trapezoid	Coiled wire	3.5 x 2.5 x 3.5	25
20	Trapezoid	Perf. Flat strap	2.5 x 2.38 x 2.5	58.75
32	Trapezoid	Coiled wire	6 x 4.5 x 5	21
48	Trapezoid	Coiled wire	6 x 4.75 x 4.5	32
50	Trapezoid	Coiled wire	6.25 x 4.75 x 4.75	32

(4) Magnesium anode typical packaging information (nominal weights & dimensions)  
 (information courtesy of Stuart Steel Protection Corporation, Bound Brook, NJ)

**Table 4 – magnesium anode physical characteristics**

Anode magnesium metal weight (pounds)	Packaged Anode weight (pounds)	Package length (inches)	Package diameter (inches)	Box length (inches)	Box width & depth (inches)	Pallet (inches)	Quantity Per pallet
1 (bagged)	4	12	3.5"	-		42 x 42	640
3 (bagged)	11	10	5	-		42 x 42	192
5 (bagged)	12	12	5	-		42 x 42	192
9 (bagged)	25	15	6	-		42 x 42	84
17 (bagged)	42	30	7	-	-	42 x 42	50
17 (boxed)	45	-	-	32	5.5	42 x 42	50
20 (boxed)	65			71	4.5	32 x 84	30
32 (bagged)	65	25	9	-	-	42 x 42	40
32 (boxed)	70	-	-	24	7.5	42 x 42	40
48 (bagged)	105	36	9	-	-	42 x 42	16
50 (bagged)	110	36	9			42 x 42	16

(5) Magnesium anode configuration notes:

(A) Standard lead wire is 10 feet of #12 awg solid copper wire with tw type insulation silver soldered to the core primed and sealed with an insulating asphalt potting compound at the factory.

(B) Standard backfill is: 75 % gypsum 20% bentonite 5% sodium sulphate

(C) Standard bag packaging consists of inner cotton bag and outer waterproof paper bag.

(D) Boxed anode backfill is vibrated during fill operation in a rigid cardboard container for maximum compaction and optimum current output.

(E) Pallets are wrapped with stretch wrap plastic. We recommend that pallets be stored under shelter for protection from the elements prior to use. Pallet covers which will keep anodes protected up to six months are available upon request.

(F) It is usually recommended that the anode lead wire be connected to structure by a thermite brazing connection, using proper recommended size charges.

(6) Anode costs

(A) The heavier the anode, the lower the cost per pound of magnesium

(B) The labor costs to install anodes is usually substantially the same regardless of the size of the anode

(C) If the cost of the metal is substantially the same, the more efficient alloy would provide a lower cost anode per ampere hour of energy

(D) installing more anodes than is absolutely required for providing the current needed for protection does not necessarily waste anode material. It generally extends the life of the anodes.

f. Magnesium Anode Advantages

(1) Very high efficiency = >90%

(2) Highest Available Driving Potential – This is an advantage in higher resistivity soils. Generally this is the only applicable anode material in soils having a resistivity of 2000 ohm-cm or higher.

(3) Lowest cost in terms of Dollars per Pound of Anode Metal and Lower in Cost vs. Magnesium Anodes in underground applications where soil resistivities are less than 2000 ohm-cm.

(4) Available for use both underground and under water applications but not generally recommended for us in salt water and soils less than 1000 ohm-centimeters resistivity due to short life in these environments.

(5) Available in the greatest number of sizes and shapes for many applications

(6) No temperature limitations (up to 212° F)

(7) Select Backfill is not required although it's use is highly recommended. If not used, lower efficiencies and selective attack of the magnesium metal will occur resulting in shorten anode operating life.

(8) No danger of potential reversal except if alloy used is “off spec” (outside alloy permissible specifications).

(9) Will almost always have lowest total galvanic anode CP cost in environments with resistivities over 2000 ohm-cm when cost of installation is included in the evaluation. The only exception to this is when the current required for a specific structure is only a few milliamperes total.

g. Magnesium Anode Limitations

(1) Relative low efficiency = approximately 50% for all alloys except AZ-63, Grade C which may be a low as 20% - 30%.

(2) Most expensive common galvanic anode metal both in \$dollar cost/pound of metal and material cost per ampere-year of corrosion protection provided

(3) Typically significantly higher material cost per ampere-year of cathodic protection provide than Aluminum Anodes in Seawater Applications.

(4) Due to high driving potential, should not be used (except under very special circumstances) in soil and waters where the resistivity is less than 1000 ohm-cm.

(5) In general, AZ-63 Alloy, Grade "C" should be avoided since this particular alloy has had numerous reported cases of passivation and even current reversal probably due to the material be "off spec" but this alloy is the most marginal quality to begin with and it is easy for one or more of the essential ingredients to be outside the acceptable limits.

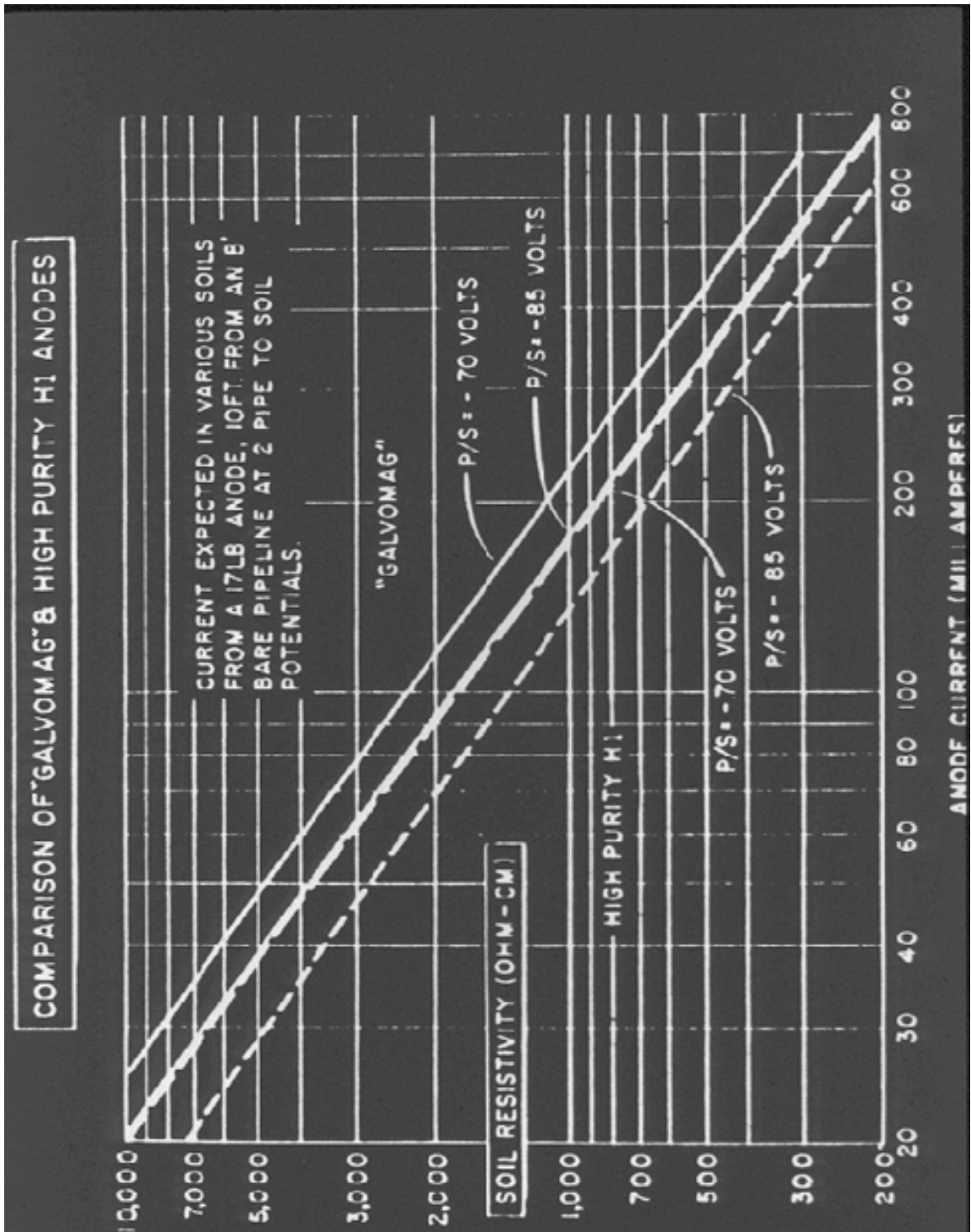
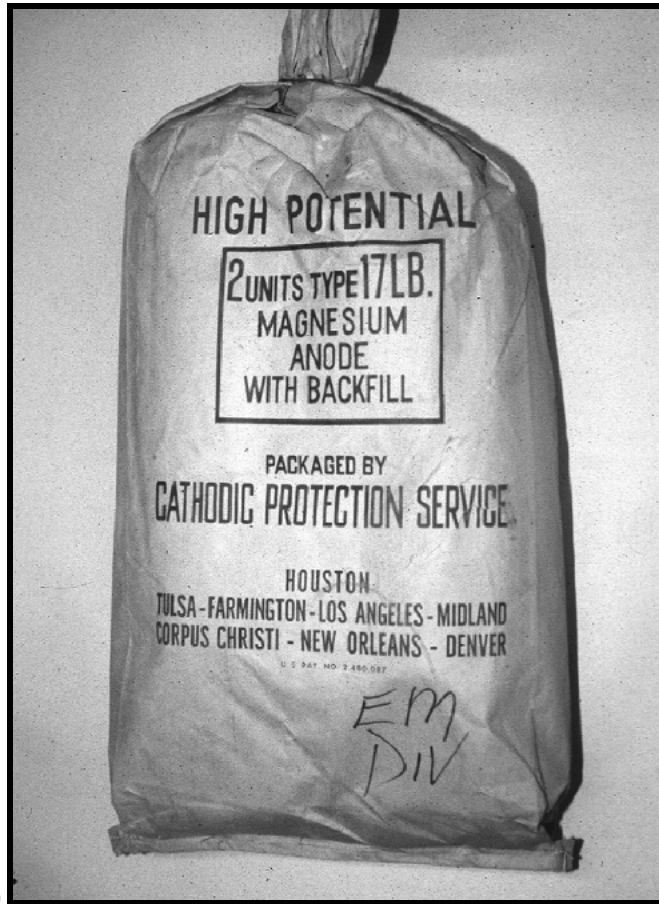


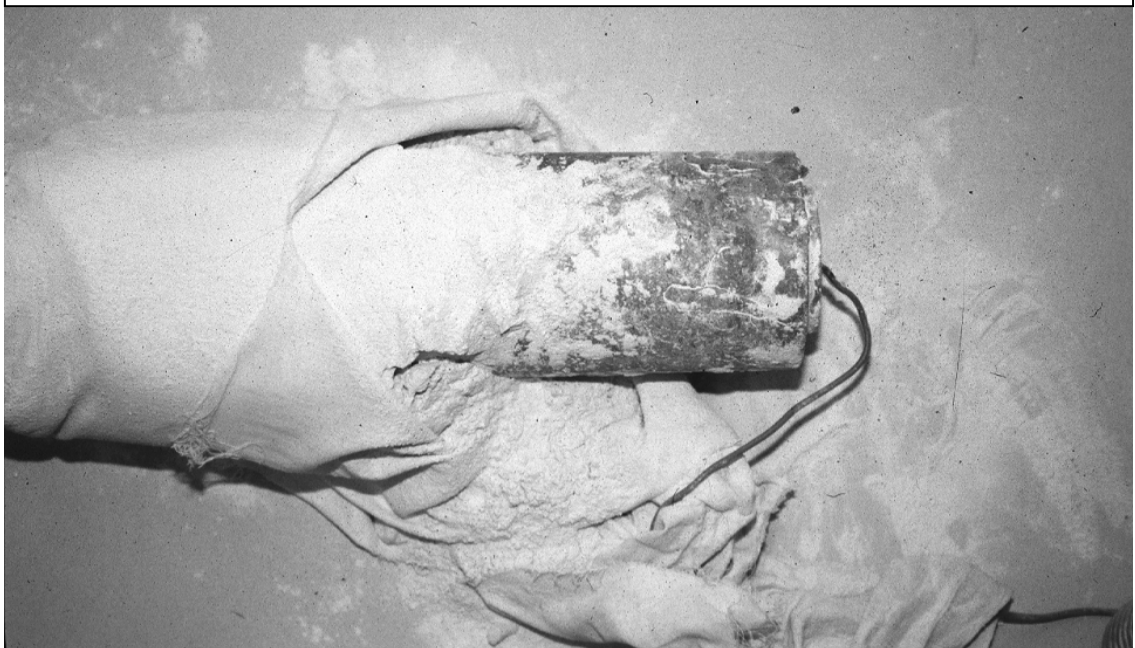
Figure 2. Current Output of H-1 Alloy and Hi-Potential Mg Anode vs Soil Resistivity

**Figure 3. Typical Bag Packaging of 2 - 17 Pound Mg Anodes**



i)

**Figure 4. Lead Wire End of Mg Anode after Opening Cotton Bag Containing Backfill**





**Figure 5. Installing Vertical Mg Anode between USTs**

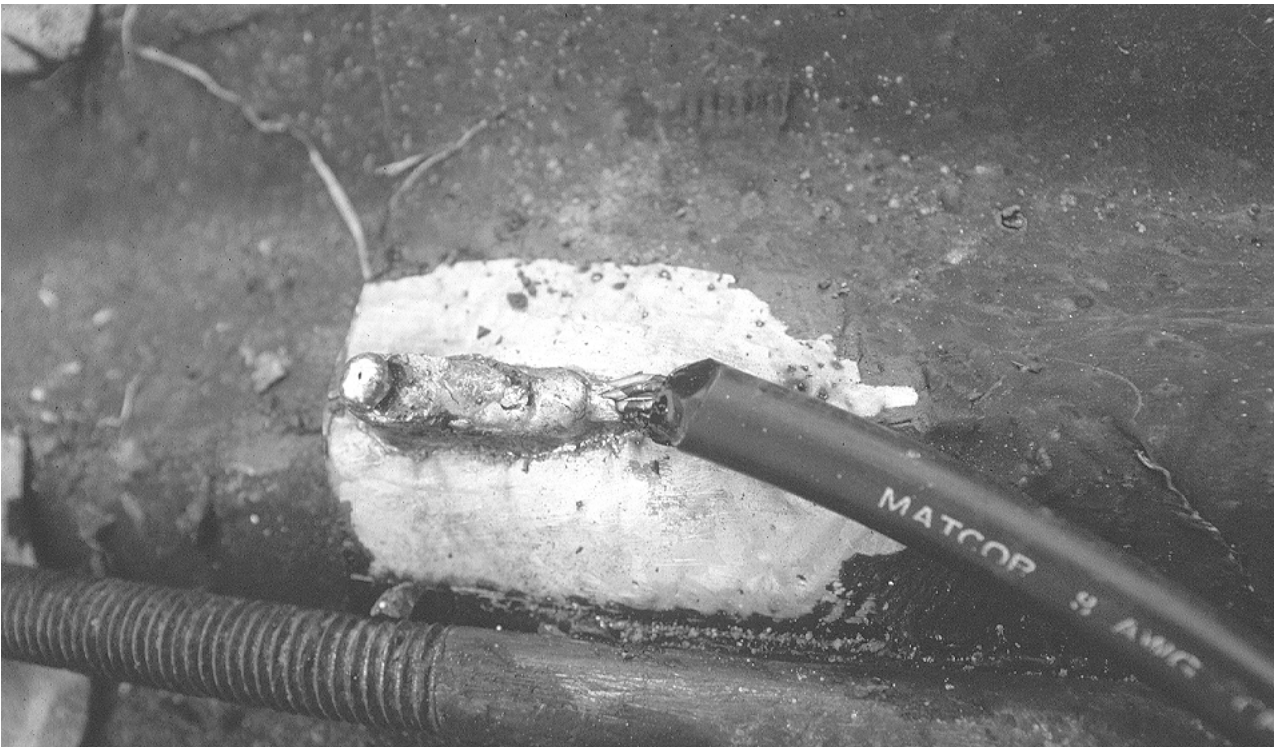


**Figure 6. Installing Horizontal Mg Anode Next to Pipe**





**Figure 7. Thermite Brazing (Cadwelding) Mg Anode Lead Wire to Pipe**



**Figure 8. Finished Thermite Braze before Coating**



**Figure 9. Pouring Waterproofing Compound over Completed Thermite Connection**

**Table 5 - Zinc Anode Chem. Analysis**

(a) Zinc for soil or fresh water uses.  
The composition limits are:

Element	Percent
Aluminum (Al)	None
Cadmium (Cd)	0.004 min.
Iron (Fe)	0.0015 max.
Lead (Pb)	0.006 max.
Copper (Cu)	0.005 max.
Total permissible impurities	0.010
Zinc (Zn)	99.99

(b) Zinc for sea water uses. The composition limits for this application are described as follows:

Element	Percent
Aluminum (Al)	0.3 max.
Cadmium (Cd)	0.06 max.
Iron (Fe)	0.003 max. <sup>1</sup>
Lead (Pb)	0.006 max.
Copper (Cu)	0.005 max.
Total permissible impurities	0.014
Zinc (Zn)	Remainder

6. Zinc Anodes

a. History – Zinc Anodes were first used in 1826 by Sir Humphrey Davies to protect the copper cladding in seawater used on wooden ships in the English Navy. This was the first use of cathodic protection to prevent corrosion of metal structures. Zinc was an ideal material in this environment because it has a very high operating efficiency and a relatively low driving voltage which is an advantage in the very conductive (low resistivity) sea water.

b. Electrochemical Properties of Zinc

- Chemical Composition – See Table 6
- Current Capacity – Theoretical  
372 amp-hours/pound or 23.5 lbs. per amp-yr
- Current Efficiency  
above 90% underground and up to 95% in sea water
- Current Capacity at 90% efficiency  
335 amp-hours/pound or 26 lbs. per amp-yr
- Potential in Sea Water or Select Backfill underground  
–1.1 volts vs. Sat. Cu-CuSO<sub>4</sub>

c. Backfills used with Zinc Anodes – Two types of select backfill are commonly used with zinc anodes. The standard backfill has a higher resistivity and is general used with anodes to be installed in very conductive soils.

**Table 6**

Select Backfill Type	Hydrated Gypsum (% by weight)	Bentonite (% by weight)	Sodium Sulfate (% by weight)	Nominal Resistivity (Ohm-Cm)
Standard	50%	50%		250
Hi-Performance	50%	20%	5%	50

d. Zinc Anode Advantages

- (1) Very high efficiency = >90%
- (2) Low Driving Potential – This is an advantage in low resistivity environments such as sea water, brackish waters and soils with resistivities less than 2000 ohm-cm.
- (3) Lowest cost in terms of Dollars per Pound of Anode Metal and Lower in Cost vs. Magnesium Anodes in underground applications where soil resistivities are less than 2000 ohm-cm.

- (4) Available for use both underground and under water (both salt and fresh waters.
- (5) Available in many size and shapes for many applications
- (6) All of the design formulae and principals of design used with magnesium anodes apply equally with zinc.

e. Zinc Anode Limitations

- (1) Must not be used in applications where temperatures exceed 120<sup>0</sup> Fahrenheit because inter-granular corrosion attack of the zinc will cause very premature failure of the material.
- (2) Susceptible to potential reversal if installed as bare anode material instead of installing with Select Gypsum-Bentonite-Sodium Sulfate Backfill in underground applications. Generally, this material should never be used underground except when installed with this Select Backfill.
- (3) Typically higher cost per ampere-year of cathodic protection provide than Aluminum Anodes in Seawater Applications.
- (4) Due to low driving potential, should not be used (except under very special circumstances) in soil resistivities greater than 2000 ohm-cm.

7. Impressed Current Cathodic Protection Systems

a. Impressed current type cathodic protection systems provide cathodic current from an external power source. A DC power forces current to discharge from expendable anodes, to the electrolyte, and onto the structure to be protected. Although the current is generated by a corrosion reaction at the auxiliary anode, the energized materials used for the auxiliary anodes either do not corrode or corrode very slowly because corrosion resistant materials and alloys are used. The primary corrosion reaction is the oxidation of negatively charge ions available around the anode and the more that this is the primary reaction, the longer the anode will last.

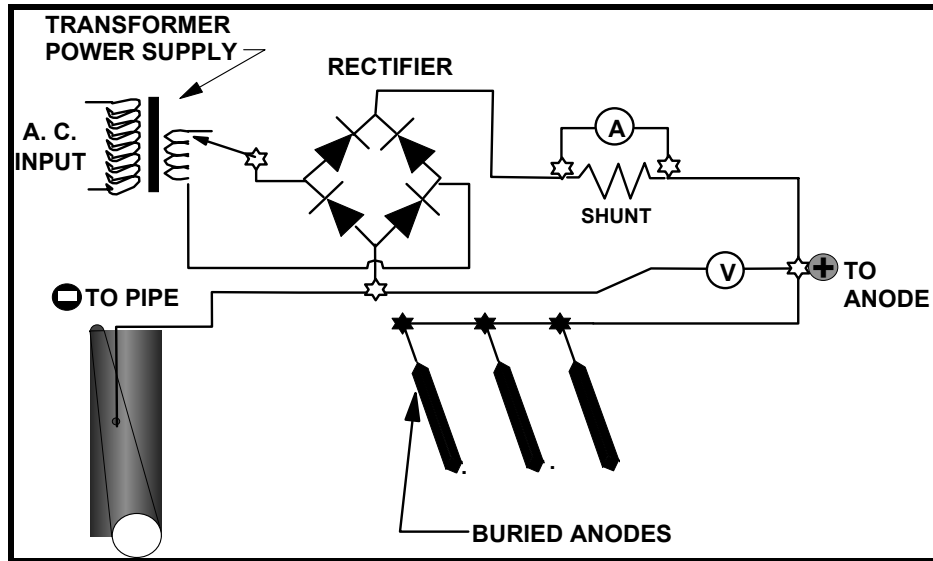
b. The three primary reactions that can occur at impressed current anode in a cathodic protection system are:

(1)  $nMe > Me^{n+} + ne^{-}$  (results in corrosion of the metal of the anode releasing n electrons for each atom of metal corroded to be delivered via the impressed current power supply to the structure to be protected)

(2)  $2Cl^{-} > Cl_2 + 2e^{-}$  (generates 1 chlorine atom for each 2 chloride ions reacted at the anode releasing 2 electrons to be delivered via the impressed current power supply to the structure to be protected)

c.  $4OH^{-} > 2H_2O + O_2 + 4e^{-}$  (generates 2 molecules of water and 1 molecule of oxygen at the anode releasing 4 electrons to be delivered via the impressed current power supply to the structure to be protected)

**Figure 10. Schematic of Impressed Current System**



d. Equation (1) will dominate if ordinary steel or other easily oxidized anode metals are used. Equation (2) usually dominates if a corrosion resistant or non-corroding anode material is used in seawater applications and deep anode beds where the hole contains salt water. Equation (3) generally dominates where a corrosion resistant anode material is used underground or in fresh water.

**Table 7 Comparative Characteristics of Galvanic and Impressed Current CP Systems**

Galvanic Anode System	Impressed Current Anode System
Fixed Voltage	Adjustable Voltage
Small Voltage	Small or Large Voltage
Fixed Current	Adjustable Current
Small Current	Small to Extremely Large Currents
Small \$/Unit Cost	Large \$/Unit Cost
Large \$/Sq. Ft. Protected	Small \$/Sq. Ft. Protected
Low Maintenance Cost	Higher Maintenance Cost
No Stray Currents	Can Cause Stray Currents

e. Essentially, there are a large number of decisions (selections) that must be made when designing an impressed current CP system. A list of the principal features, all of which need to be addressed, are as follows:

(1) Type of Ground Bed

- (a) banked
- (b) distributed
- (c) deep

(2) Anode Material

- (a) Type of Anode Material
- (b) Graphite
- (c) High Silicon Cast Iron
  - i. Standard
  - ii. Chromium/Molybdenum Alloy
- (d) Platinum Coated Titanium and Niobium
- (e) Ceramic Coated Titanium (also called Precious Metal Oxide coated)

(3) Anode Shape

(4) Anode Wire

- (a) Method of Anode Connection
- (b) Wire Size & Insulation

(5) Anode Canister Prepackaging

(6) Anode Backfill

- (a) Backfill Type
- (b) Granular Size
- (c) Inside, outside or both

(7) Number of Anode Elements Required

- (a) For required life for required life
- (b) For maximum allowable ground bed resistance

f. Rectifier Type

(1) Cooling

- (a) convection air
- (b) oil immersed

(2) Control

- (a) tap adjusted voltage
- (b) dial adjusted voltage
- (c) constant current control

- (d) constant potential control (with IR-drop correction?)
- (3) Cabinet Material and Finish
- (4) Rectifier DC Output Capacity
  - (a) Amperes
  - (b) Volts
- (5) AC Power Requirements and Source Location
- (6) Rectifier Mounting
  - (a) Outside or Indoors
    - i. Pole mounted
    - ii. Pad mounted
    - iii. Wall mounted
- (7) Rectifier Options
  - (a) Type of stack material (selenium or silicon)
  - (b) Lightning protection
    - i. Type (e.g. Gaseous, MOV, Spark Gap)
    - ii. AC, DC or both sides
  - (c) Fuses and circuit breakers
    - i. AC, DC or both
  - (d) Meters
    - i. Digital or analog
    - ii. Separate V & A or single with selector switch
    - iii. Up time output monitor/hour meter
- (8) System Negative Connection to Structure
  - (a) Above Grade
  - (b) Below Ground
  - (c) Thermite Brazing (Cadwelding or Thermowelding)
  - (d) Welding
  - (e) Mechanical Connectors including Clamps, Bolts, Etc.
- (9) Remote monitoring system

g. While it can be seen from the above that there are numerous decisions to be made, the most fundamental aspect of the design will involve selection of the anode material to be used.



h. Components of an impressed current ground bed can be divided into two categories, those which are essential and those which are ancillary.

(1) Essential components are those necessary to transfer rated direct current from a D.C. power source into the electrolyte for the design life of the system. They include:

- (a) Anode.
- (b) Anode lead wire including lead wire connection method and moisture seal
- (c) Low resistance carbonaceous backfill.

(2) Ancillary components are other components that facilitate installation, center the anode in the backfill column, prevent caving of the side wall of drilled anode holes, seal off selected soil formations and/or aquifers, assist in venting produced gases to the atmosphere, etc. These components may or may not enhance performance of the ground bed. They include:

- (a) Anode ground bed header cable (generally these is only used where they can not be avoided)
- (b) Surface anode metallic canisters for pre-packaging coke breeze around anodes
- (c) Perforated vent pipes in deep anode beds
- (d) Metallic and non-metallic surface casing for deep anode beds
- (e) Anode centering devices
- (f) Anode support pipes for deep anode beds
- (g) Anode weights for deep anode beds
- (h) Bentonite or cement “plugs” to prevent transfer of water between aquifers in deep anode beds.

i. Commonly used impressed current anodes can be divided into two main groups, that is those with relatively higher consumption rates and those with relatively low consumption rates. The first group includes all metallic anodes that have consumption rates measured in pounds per ampere of current delivered each year and the second group that have consumption rates either measured in grams per ampere-year of operation or have no measurable consumption rate.

(1) Higher Consumption Rate Impressed Current Anodes

- (a) Graphite Anodes
- (b) Scrap Iron and Steel were the first impressed current cathodic protection anode materials. Unfortunately, they were consumed at the predictable Faradaic rate for Fe of 20.1 pounds per ampere-year of direct current generated. In the 1940's, Union Carbide Corporation experimented with the use of graphite rods that were being manufactured for use in other

electrochemical applications in cathodic protection applications. The anode material solved many of the problems associated with the use of scrap iron and steel and quickly became the impressed anode material of choice. It maintained this leadership position until the 1970's when the development of Hi-Silicon Cast Iron Anodes gained dominant market acceptance.

(c) Graphite Anodes are made by transforming green carbon anode shapes into graphitic carbon at a very high temperature in an environment free of oxygen.

(d) Graphite anodes are porous, readily absorbing moisture which accelerates consumption of the material and can cause the electrical connection to the copper lead wire within the anode to fail due to corrosion. To prevent this, graphite anodes must be impregnated with moisture proofing materials. Some of the impregnating materials commonly used include linseed oil, micro-crystalline wax, poly-formaldehyde resin and epoxy.

(e) The general properties of graphite are:

**Table 8**

<b>Chemical Property</b>	<b>Weight (% of Total)</b>
Impregnate	6.5 max.
Ash	1.5 max.
Moisture & Volatiles	0.5 max.
Water soluble material	1.0
Graphitic Carbon	remainder

**Table 9**

<b>Physical Property</b>	<b>Value</b>
Density	99.84 lb/ft <sup>3</sup> max
Resistivity	10 <sup>-4</sup> Ω-cm max

(f) The cable connection to the anode must be waterproof and should be able to withstand a pull of 325 pounds.

(g) Consumption Rate

(i) When installed underground in carbonaceous backfill = 1 – 3 pounds/ampere-year

- Current output must be limited to 0.5 amperes per square foot of anode surface area or 2 amperes maximum for a 3" diameter x 60" long rod anode and 0.25 amperes/ft<sup>2</sup> to achieve rate less than 1 pound/ampere-year.

(ii) Fresh water – Do Not Use graphite anodes in Fresh or Brackish Water with less than 5000 mg/L chloride ions.

(iii) Submerged in Salt Water = 0.5 – 3 pounds/ampere-year

- Current output must be limited to 1.5 amperes per square foot of anode surface area or 6 amperes maximum for a 3” diameter x 60” long rod anode and 0.75 amperes/ft<sup>2</sup> to achieve rate less than 1 pound/ampere-year.

**Table 10 - Typical Graphite Rod Sizes**

Dia. (inches)	Length (inches)	Weight after Treatment (Pounds)	Surface Area (Sq. Ft.)	Typical Operating Ampacity (Buried in Coke Breeze)	Typical Operating Ampacity (Submerged in Sea Water)
3	30	13.5	2	0.5	1.5
3	60	27	4	1.0	3.0
4	40	35	3.5	0.9	2.6
4	80	69	7	1.8	5.3
6	36	70	4.9	1.2	3.7
6	72	140	9.8	2.4	7.3

(h) Graphite Anodes Advantages:

- Readily available in a variety of sizes
- Lowest first cost impressed current anode material
- High ratio of surface area to weight enhances low current density current discharge and low resistance to electrolyte
- Does not form a high resistance layer of corrosion product
- Environmentally safe.

(i) Graphite Anodes Disadvantages:

- Can not be used in fresh water
- Must be installed in Carbonaceous backfill in underground applications
- Cathodic protection anode grade material is relatively weak and subject to breakage
- “Black Body” effect of graphite magnifies thermal expansion problems with metallic lead wire connectors and resin sealing material which can result in cracking of the anode in high ambient temperature desert summer environments

- (v) Proper impregnation of graphite anodes with linseed oil can only be accomplished in an autoclave.
  - (vi) The anodes are consumed over time when operated as an anode. Overall dimensions decrease and resistance to electrolyte increases with time.
- (j) High Silicon Cast Iron Anodes
- (i) Hi-Silicon Cast Iron Anodes were first developed by the Duriron Company of Dayton, Ohio in the late 1950's and early 1960's. This anode material evolved from a material that was used to cast corrosion resistant laboratory sinks and chemical pumps. The initial alloy used for underground anodes was named the Duriron anode which was made from primarily 14.5% Silicon Cast Iron. The alloy soon gained market acceptance and became the dominant alloy until the 1970's when they developed the Durichlor 51 Alloy.
  - (ii) The Durichlor 51 alloy was developed in response for the need for an anode which would work better in sea water immersion applications. Ordinary Duriron alloy suffered accelerated, selective attack in sea water. The new alloy, which included the addition of chromium and molybdenum to the original Duriron alloy, provided significantly reduced consumption rates when operated at reasonable current outputs in sea water applications.
  - (iii) In the late 1970's, the Duriron Company stopped manufacturing Duriron Alloy anodes substituting the Durichlor 51 alloy for all CP applications. Their standard rationale for this was that they didn't want to maintain two alloys in stock and that the added cost of the Durichlor 51 alloy would be offset by the reduced inventory costs. It should be noted, however, that their patents on the ordinary Duriron alloy had run out while the Durichlor 51 alloy patents still had a significant number of years to run.
  - (iv) The Hi-Silicon Cast Iron Anode was first manufactured by the green sand mold casting technique. The anode was first cast in rod form with a cavity at one end for making an expanded lead connection of the lead wire to the casting. Because the material was very brittle, about the smallest diameter rod that could practically be cast in longer lengths (typically 60" long rods) was 1 inch. More typically, the anodes had rod diameters of 1.5 to 2 inches in order to keep shipping and handling breakage to a minimum
  - (v) All rod shape anodes tend to be consumed at a higher rate at the ends. Since that was where the connection was made on these anodes, premature failure could occur. To reduce this effect, the manufacturer cast the rods with expanded head(s) where the connection was to be made. This helped somewhat although the increased diameter resulted in even higher current discharge at the "belled" end somewhat offsetting the benefit of greater mass of metal at the bell.
  - (vi) Advantages of High Silicon Chromium Anodes include:
    - Available in a wide variety of sizes and weights
    - Perform well in wet locations, and suspended in water without backfill

- Relatively inexpensive
  - High ratio of surface area to weight of tubular anodes enhances low current density discharge and low contact resistance to electrolyte
- (vii) Disadvantages of High Silicon Chromium Anodes include:
- High weight per unit volume, this results in higher freight costs and higher labor costs to install in deep ground beds
  - Relatively high wear rates when installed without carbonaceous backfill and also when installed with carbonaceous backfill after SiO<sub>2</sub> film forms and eliminates direct anode metal to backfill contact
  - Formation of SiO<sub>2</sub> film can result in very high anode-to-electrolyte resistance except in aqueous electrolytes
  - Brittle anode material subject to breakage
  - High silicon cast iron not alloyed with chromium has extremely high wear rates in seawater or produced brines
  - Integrity of anode lead wire-to-anode connection dependent on resin or mastic seal
  - The anodes are not dimensionally stable, thus overall dimensions decrease and resistance to electrolyte increases with time

## (2) Low Weight Loss Anodes

### (a) Platinum Clad Titanium and Niobium Anodes

- (i) Most anodes consist of 25 to 100 micro inches (0.00063 mm to .00254 mm) of platinum plated or clad by co-extrusion onto a substrate of titanium or niobium
- (ii) Rate of deterioration is:
- Seaweed 8 mg/amp-yr.
  - Neutral soil (oxygen environment) 40 to 80 mg/amp-yr.
- (iii) Breakdown voltage of titanium dioxide is:
- Seawater 12 volts
  - Fresh water and neutral soil 60 volts
- (iv) Advantages of Platinum are:
- Strong and Flexible
  - Low breakage rate
  - Light weight
  - Low wear rate in free flowing seawater

- Reasonable wear rates in fresh water
- Dimensionally stable
- Do not form a high resistance film

(v) Disadvantages of Platinum are:

- Not normally available from stock except in 0.031" and 0.062" diameter wire
- High initial cost
- Higher wear rates in O<sub>2</sub> evolving electrolytes
- High wear rates at elevated temperatures
- High wear rates in the presence of certain hydrocarbons
- Subject to failure from low frequency AC ripple and ½ wave rectified DC current flows
- Subject to failure from prolonged current reversal

(b) Mixed Metal Oxide (Ceramic) Coated Titanium Anodes

(i) Consist of electro-catalytic coatings applied by thermal decomposition to specially prepared titanium substrates. The electro-catalytic coatings are formulated primarily of platinum group metals and appropriate binders. The coatings are applied by spraying or dip coating aqueous salts of the metals onto an acid etch cleaned titanium substrate and heating to several hundred degrees Celsius. Multiple layers of coating may be applied by this process to provide the desired final coating thickness.

(ii) The resulting mixed metal oxide coating is:

- Highly conductive (10<sup>-3</sup> Ω-cm to 10<sup>-6</sup> Ω-cm resistivity)
- Crystalline (anhydrous)
- Corrosion and Acid resistant
- Hardness of 60
- High abrasion resistance

(iii) Precious metal oxide (ceramic) coated titanium or niobium wire anode material is available in a variety of configurations for optimization of specific CP requirements. It is a ceramic-metal multi-layer composite that is ductile, rugged and easy to use. It consists of an ultra thin layer of an iridium-tantalum-titanium, mixed metal oxide ceramic deposited onto either a solid titanium core (STI version), a copper cored titanium interface (CTC) or a copper cored niobium-titanium interface (CNC version). The latter has a niobium interface for CP applications requiring the added assurance of niobium voltage breakdown characteristics. However, the unique characteristics of some of these anodes manufactured with a chemical bond

interface effectively reduces the interface voltage rarely making the niobium interface necessary. The wire is available in nominal standard diameter sizes of 1/16" (1.5mm) or 1/8" (3mm).

- (iv) The very thin precious metal oxide anode coating is exceptionally durable in combination with the ductile commercially pure titanium substrate. It has been tested at current densities over 2000 amperes per square foot of anodic current discharge. It is fabricated from primarily of precious metal and refractory metal oxides in sufficient quantities and ratios to provide a defined life expectancy. Because the coating is already oxidized, it is not consumed when operating as an anode in cathodic protection applications and is dimensionally stable. This dimensional stability is a major advantage in that the resistance to earth does not increase with time as it does with other more consumable anodes such as HSCI or Graphite. Since ceramic coating will support the evolution of both oxygen and chlorine, it can be a good choice for fresh water, seawater, mud, brackish water and coke environments.
- (v) Available Wire Types – All impressed current cathodic protection anodes should be provided with stranded (7 strands minimum), annealed copper lead wire. High Molecular Weight, Low Density Polyethylene (HMWPE) is the most popular anode lead wire insulation, however both Kynar/HMWPE and Halar/HMWPE dual extrusion insulations are available for more demanding situations where chlorides, oil or other harsh environments are involved. Other cable insulations have been used including EPR/CSPE (ethylene propylene rubber/chloro-sulphonated polyethylene commonly called Hypalon) are available when suitable for the application. It is important that the appropriate cable be engineered for the environment. Free chlorine gas is generated at the anode in a chloride environment which is very aggressive in attacking common plastic insulations.
- (vi) Waterproof Connection - As with all other anodes, if moisture penetrates into the anode/lead wire connection area, the connection will begin to corrode rapidly and anode failure will quickly result. Thus, tubular anode shape wherein the connection can be made deep down inside the tube are favored in more aggressive environments and deep anode beds where high external water pressures may be encountered.
- (vii) Anode Connection Resistance - Lead wire connection resistance can be a major factor when using this anode material in high current discharge applications. It can be obtained with swaged or soldered connections which provide connection resistance's of less than 0.001 ohms.
- (viii) Advantages of Mixed Metal Oxide Ceramic Coated Titanium/Niobium Anodes are:
- Strong and ductile
  - Very low breakage rate
  - Light weight

- Available in the largest number of sizes and shapes available of any anode
- Highest amperage capacity and life in free flowing seawater
- Very good amperage capacity and life in fresh water applications and underground when installed in coke breeze.
- Dimensionally stable
- Does not form a high resistance film
- Resistant to acids
- Generally the lowest cost/A-yr of all anodes when operated at rated output.

(ix) Disadvantages of Titanium/Mixed Metal Oxide Anodes are:

- May have initial higher cost compared to other equivalent anodes in some sizes and shapes.
- Heavy duty coatings required to perform well in O<sub>2</sub> evolving electrolytes
- Should not be used in electrolytes with pH over 11.5
- Temperature range for maximum performance limited to range between 33° F and 175° F (17.2° C to 79.4° C)

**Table 11 – Ceramic Anode Wire Sizes And Output Capacities  
In Salt, Brackish & Fresh Waters for 20-Year Life**  
(Information Courtesy Of Ceranode Technologies International, Dayton, Ohio)

Dia- meter	Type Sub- strate	Ceramic Coating Current Capacity	Current Capacity in Fresh Water (A/Lin. Ft.)	Current Capacity in Brackish Water (A/Lin. Ft.)	Current Capacity in Sea Water (A/Lin. Ft.)	Anode Longitudinal Resistance (Ohms/Lin. Ft.)
<b>1/16"</b>	Solid Titanium (ST)	Ultra Low	0.012	0.018	0.031	0.088
<b>1/16"</b>	ST	Extra Low	0.025	0.038	0.062	0.088
<b>1/16"</b>	ST	Low	0.050	0.075	0.125	0.088
<b>1/16"</b>	ST	Regular	0.100	0.150	0.250	0.088
<b>1/16"</b>	ST	High	0.200	0.300	0.500	0.088
<b>1/16"</b>	Copper Cored Titanium (CCT)	Ultra Low	0.012	0.018	0.031	0.0053



Dia-meter	Type Substrate	Ceramic Coating Current Capacity	Current Capacity in Fresh Water (A/Lin. Ft.)	Current Capacity in Brackish Water (A/Lin. Ft.)	Current Capacity in Sea Water (A/Lin. Ft.)	Anode Longitudinal Resistance (Ohms/Lin. Ft.)
1/16"	CCT	Extra Low	0.025	0.038	0.062	0.0053
1/16"	CCT	Low	0.050	0.075	0.125	0.0053
1/16"	CCT	Regular	0.100	0.150	0.250	0.0053
1/16"	CCT	High	0.200	0.300	0.500	0.0053
1/16"	Copper Cored Titanium/Niobium (CCTN)	Ultra Low	0.012	0.018	0.031	0.0053
1/16"	CCTN	Extra Low	0.025	0.038	0.062	0.0053
1/16"	CCTN	Low	0.050	0.075	0.125	0.0053
1/16"	CCTN	Regular	0.100	0.150	0.250	0.0053
1/16"	CCTN	High	0.200	0.300	0.500	0.0053
1/8"	ST	Ultra Low	0.025	0.038	0.062	0.022
1/8"	ST	Extra Low	0.050	0.075	0.125	0.022
1/8"	ST	Low	0.100	0.150	0.250	0.022
1/8"	ST	Regular	0.200	0.300	0.500	0.022
1/8"	ST	High	0.400	0.600	1.000	0.022
1/8"	CCT	Ultra Low	0.025	0.038	0.062	0.00095
1/8"	CCT	Extra Low	0.050	0.075	0.125	0.00095
1/8"	CCT	Regular	0.200	0.300	0.500	0.00095
1/8"	CCT	High	0.400	0.600	1.000	0.00095
1/8"	CCTN	Ultra Low	0.025	0.038	0.062	0.00095
1/8"	CCTN	Extra Low	0.050	0.075	0.125	0.00095
1/8"	CCTN	Low	0.100	0.150	1.000	0.00095
1/8"	CCTN	Regular	0.200	0.300	0.500	0.00095
1/8"	CCTN	High	0.400	0.600	1.000	0.00095

**Manufacturers Notes:**

- 1) WHEN USING A LONG SLENDER ANODE, THE DESIGN MUST NOT ALLOW EXCESSIVE VOLTAGE ATTENUATION OVER THE ANODE LENGTH. FOR VOLTAGE ATTENUATION OF <10% AT THE ROD END OPPOSITE FROM THE CONNECTION, THE RATIO OF ROD METALLIC RESISTANCE TO ANODE/ELECTROLYTE RESISTANCE MUST BE <0.22.
- 2) TOTAL IMMERSION IN WATER. REDUCE CURRENT 50% FOR OPERATION BELOW 10 DEGREES C. ELECTROLYTE IMPURITIES MAY ALSO AFFECT ANODE LIFE.
- 3) FOR OPTIMAL ANODE-TO-EARTH INTERFACE USE LORESCO<sup>®</sup> DW-1, SC-2, SC-3, FLEXFILL OR EQUAL. THE INDUSTRY ACCEPTED CURRENT DENSITY AT THE COKE TO EARTH INTERFACE IS 100 -200MA/SQ FT. FOR BEST RESULTS DO NOT EXCEED 100 - 140 AMP/M<sup>2</sup> AT THE ANODE-TO-COKE INTERFACE.

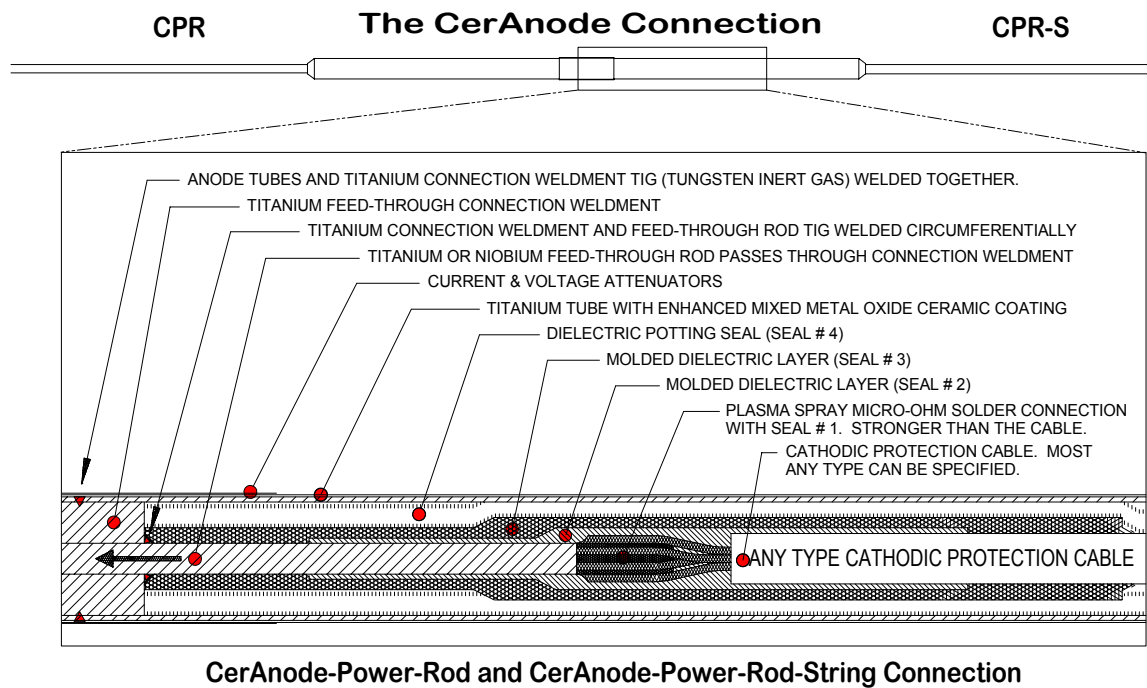
**Table 12 –Ceramic Tubular Anode Sizes and Ampere Capacities**

Ceramic Coating Current Capacity	Environment	Anode Length (inches)	Anode Diameter (inches)	Anode Weight (Lbs.)	Ampere Capacity	Life at Rated Ampacity
High	Fresh Water	20	0.75	0.75	2.5	20
High	Fresh Water	24	0.75	0.9	3	20
High	Fresh Water	40	0.75	1.5	5	20
High	Fresh Water	48	0.75	1.8	6	20
High	Fresh Water	20	1.0	1.0	4	20
High	Fresh Water	40	1.0	2.0	8	20
Standard	Fresh Water	60	1.0	3.0	5	20
Standard	Fresh Water	90	1.0	4.0	7.5	20
Standard	Fresh Water	120	1.0	5.0	10	20
High	Fresh or Brackish Mud	20	1.0	1.0	3*	20
High	Fresh or Brackish Mud	40	1.0	2.0	6*	20
High	Sea Water	20	0.75	0.75	15	15
High	Sea Water	40	0.75	1.5	30	15
High	Sea Water	20	1.0	1.0	25	15
High	Sea Water	40	1.0	2.0	50	15
High	Sea Water Mud	20	1.0	1.0	4*	15
High	Sea Water Mud	24	0.75	0.9	3*	15
High	Sea Water Mud	40	1.0	2.0	8*	15
High	Sea Water Mud	48	0.75	1.8	6*	15

Manufacturers Notes:

\* Reduce current 50% for operation below 10 degrees C. Impurities may also affect rating.

**Figure 11. Typical Tubular Ceramic Anode Connection**  
 Courtesy of CerAnode Technologies, International – Dayton, Ohio



**Table 13 - Canistered Ceramic Anode Characteristics  
For Underground Applications**

Information Courtesy of CerAnode Technologies, International – Dayton, Ohio

<b>Canister Anode Characteristic</b>	<b>Max. Current Rating (Amperes)</b>	<b>Current Rating (Amperes)</b>	<b>Current Rating (Amperes)</b>	<b>Current Rating (Amperes)</b>	<b>Current Rating (Amperes)</b>
For 20 Year Life	0.5	1.0	2.0	3.5	4.0
For 15 Year Life	0.6	1.2	2.5	4.3	5.0
For 10 Year Life	0.75	1.5	3.0	5.2	6.0
Canister Size:	3" x 40"	3" x 60"	3" x 60"	3" x 60"	4" x 80"
Canister Weight <sup>1</sup> :	18 Lbs.	22 Lbs.	22 Lbs.	22 Lbs.	30 Lbs.
Hole/Coke Column Size:	4" x 60"	4" x 80"	8" x 80"	12" x 80"	12" x 100"
	Groundbed Resistance <sup>2</sup> (Ohms)	Groundbed Resistance <sup>2</sup> (Ohms)	Groundbed Resistance <sup>2</sup> (Ohms)	Groundbed Resistance <sup>2</sup> (Ohms)	Groundbed Resistance <sup>2</sup> (Ohms)
1000 ohm-cm Soil Resistivity	4	3.2	2.6	2.3	2.0
3000 ohm-cm Soil Resistivity	12	9.5	7.9	7.0	6.0

**Manufacturers Notes:**

- A significant portion of canister weight is high carbon, fine particle size, calcined petroleum coke earth contact backfill.
- These Groundbed Resistance numbers were calculated by the manufacturer using the canister dimensions as the anode element dimensions in H. B. Dwight's equation for resistance to earth of a single vertical ground anode. Actual resistance will vary depending on the contact resistance of the anode element to the coke breeze in the canister and the spacing between anodes assuming multiple anodes are used..
- Minimum recommended coke column (hole size). The smaller the hole diameter the less expensive the ground bed. However, for good groundbed life the outer surface area of the coke column must be sized (as above) to provide a current density at the coke to earth interface of no more than 0.15 Amp/Ft<sup>2</sup>. This helps to insure electronic conduction from the anode to coke and then to the earth as opposed to ion conduction. To the degree ionic conduction is involved, the volume of coke required for a 20 year design must be based on the coke consumption rate. A rule of thumb is 2.2 lb/amp-yr at a current density of 0.09 Amp/Ft<sup>2</sup> but this number is electrolyte dependent.