

# Oil and Gas Pipeline Design, Maintenance and Repair

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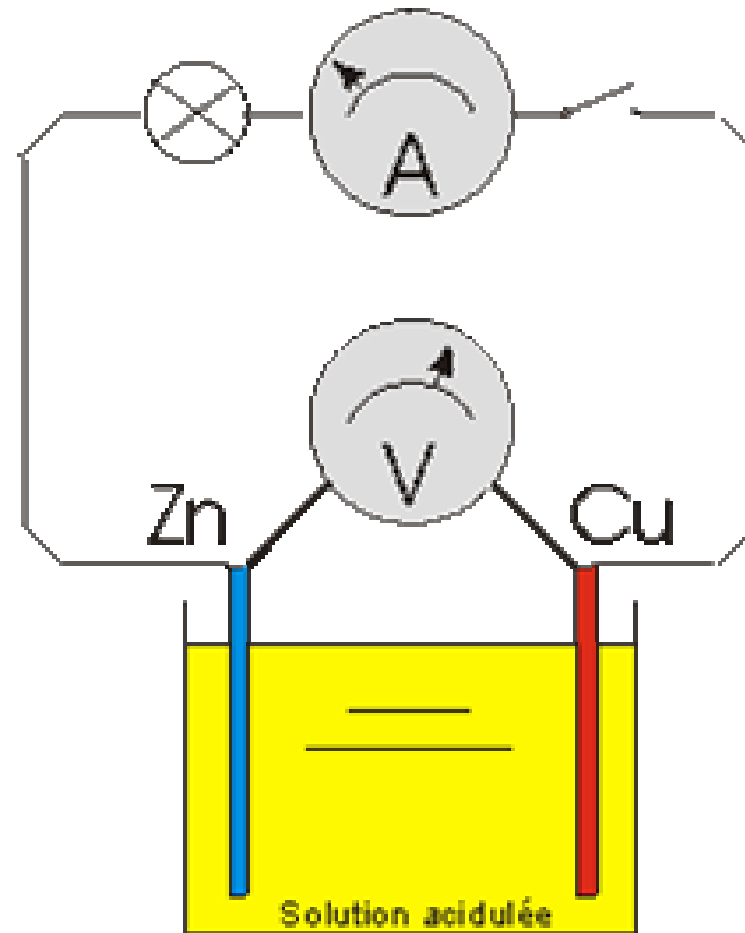
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## Part 10: Corrosion in Pipeline

# OVERVIEW

- Corrosion is the reaction of a metallic material with its environment.
- In all electrolytes, as for example, in the ground, in river or sea water metal atoms go into solution as electrically charged ions during the corrosion reaction.
- This process produces a more or less rapid loss of metal surfaces.
- The movement of charged ions causes a flow of electric current.
- This flow of electrons results in a current flowing from the metal to the electrolyte.

# ECLECTIC CELL



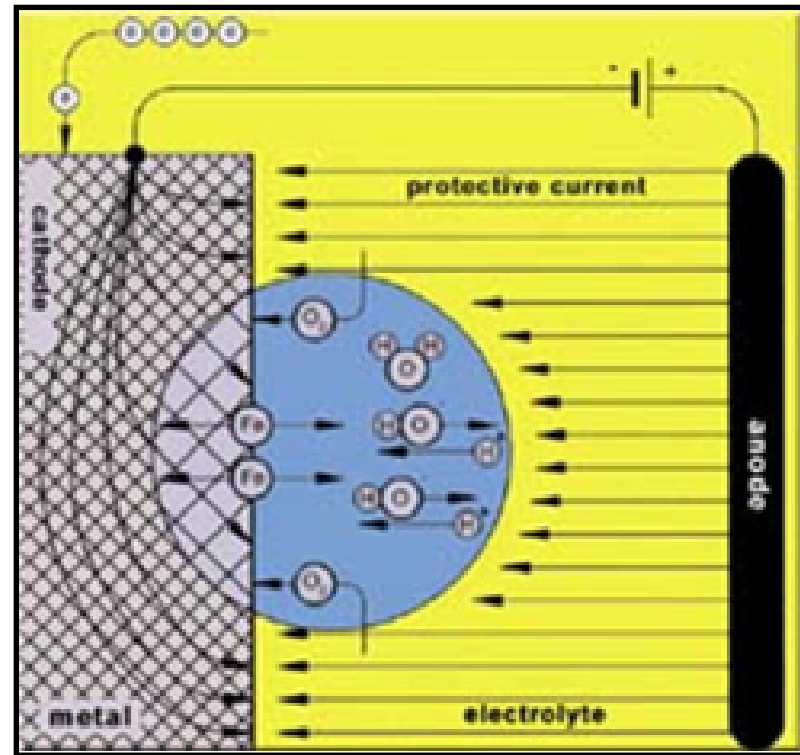
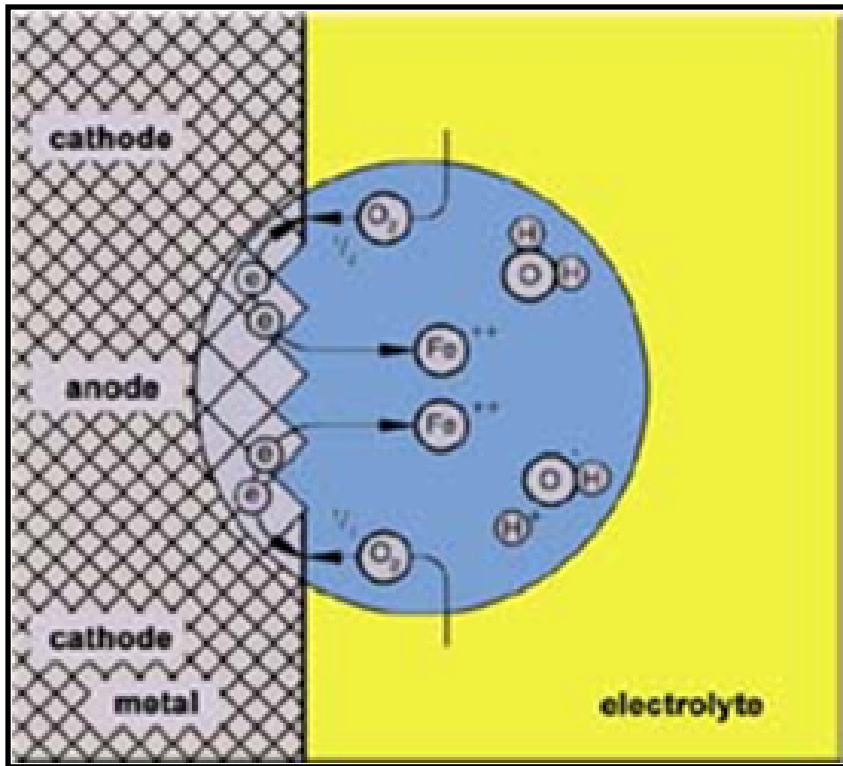
# EXAMPLE OF CORRODED PIPE



# EXAMPLE OF CORRODED PIPE



# CATHODIC PROTECTION

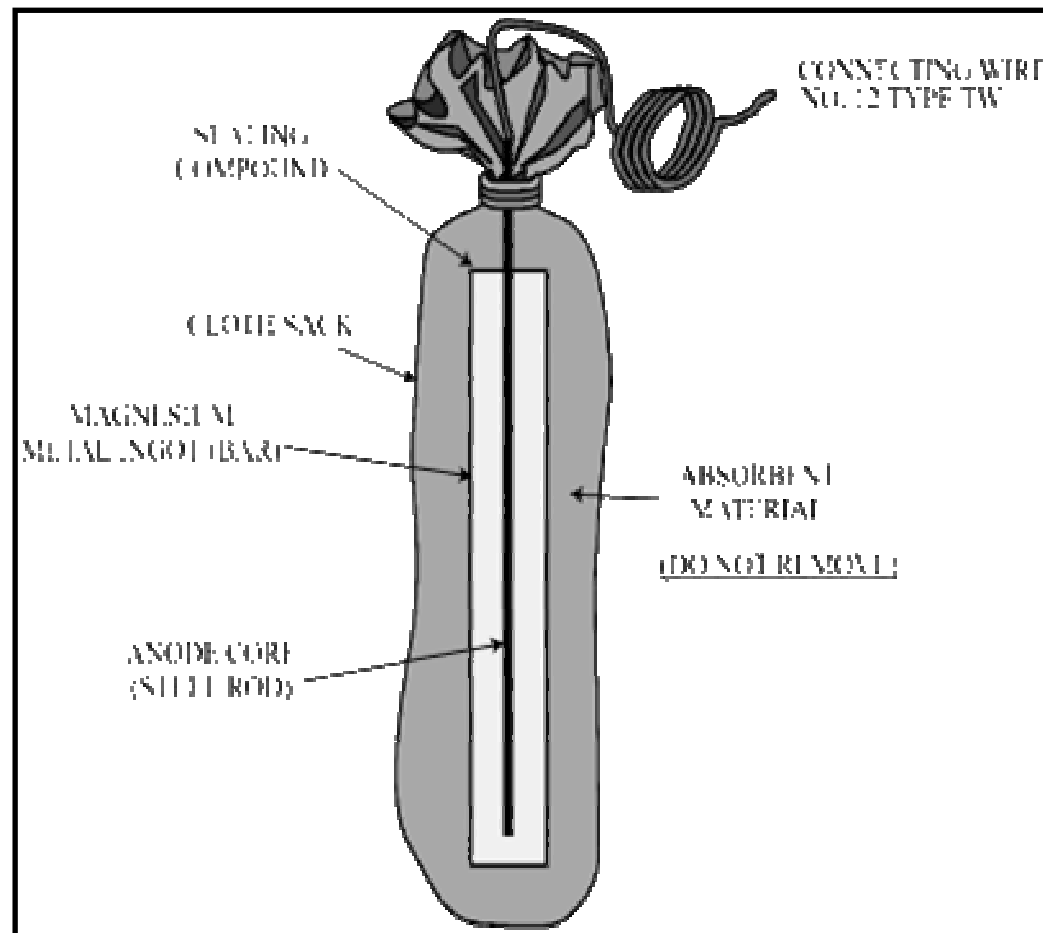


a: Anodic reaction:  $\text{Fe} \rightarrow \text{Fe}^{2+} + 2\text{e}^-$       b: Cathodic reaction:  $\frac{1}{2}\text{O}_2 + \text{H}_2\text{O} + 2\text{e}^- \rightarrow 2\text{OH}^-$

# BASIC TERMS

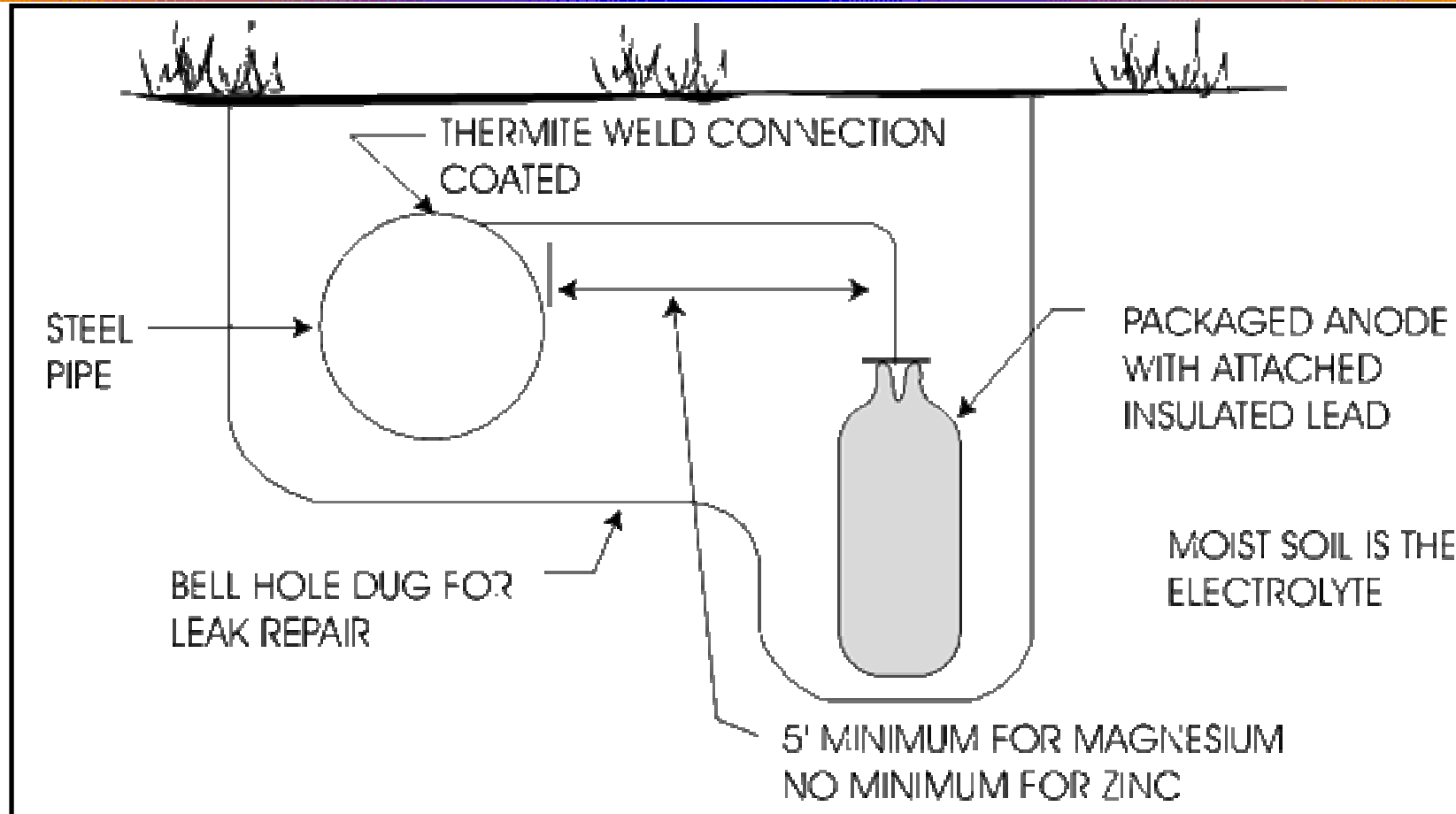
- **Corrosion** is the deterioration of metal pipe, caused by a reaction between the metallic pipe and its surroundings.
- **Cathodic protection** is a procedure by which an underground metallic pipe is protected against corrosion. A direct current is impressed onto the pipe by means of a sacrificial anode or a rectifier.
- **Anode (sacrificial)**: an assembly of a bag usually containing a magnesium or zinc ingot and other chemicals, which is connected by wire to an underground metal piping system.
- **Sacrificial protection** means the reduction of corrosion of a metal in an electrolyte by galvanically coupling the metal (steel) to a more anodic metal (magnesium or zinc)

# TYPICAL MAGNISUM ANODE

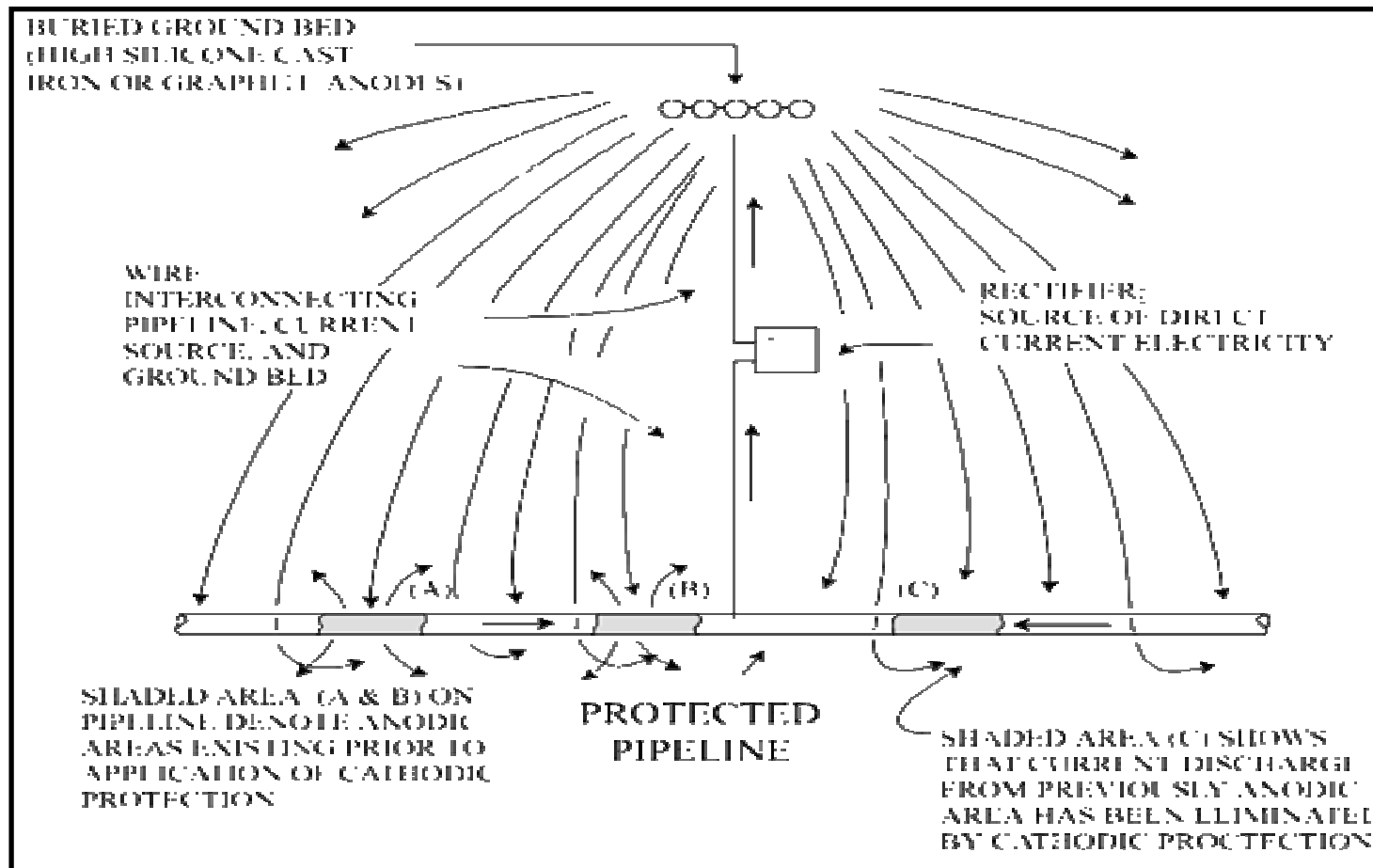




# SACRIFICIAL PROTECTION



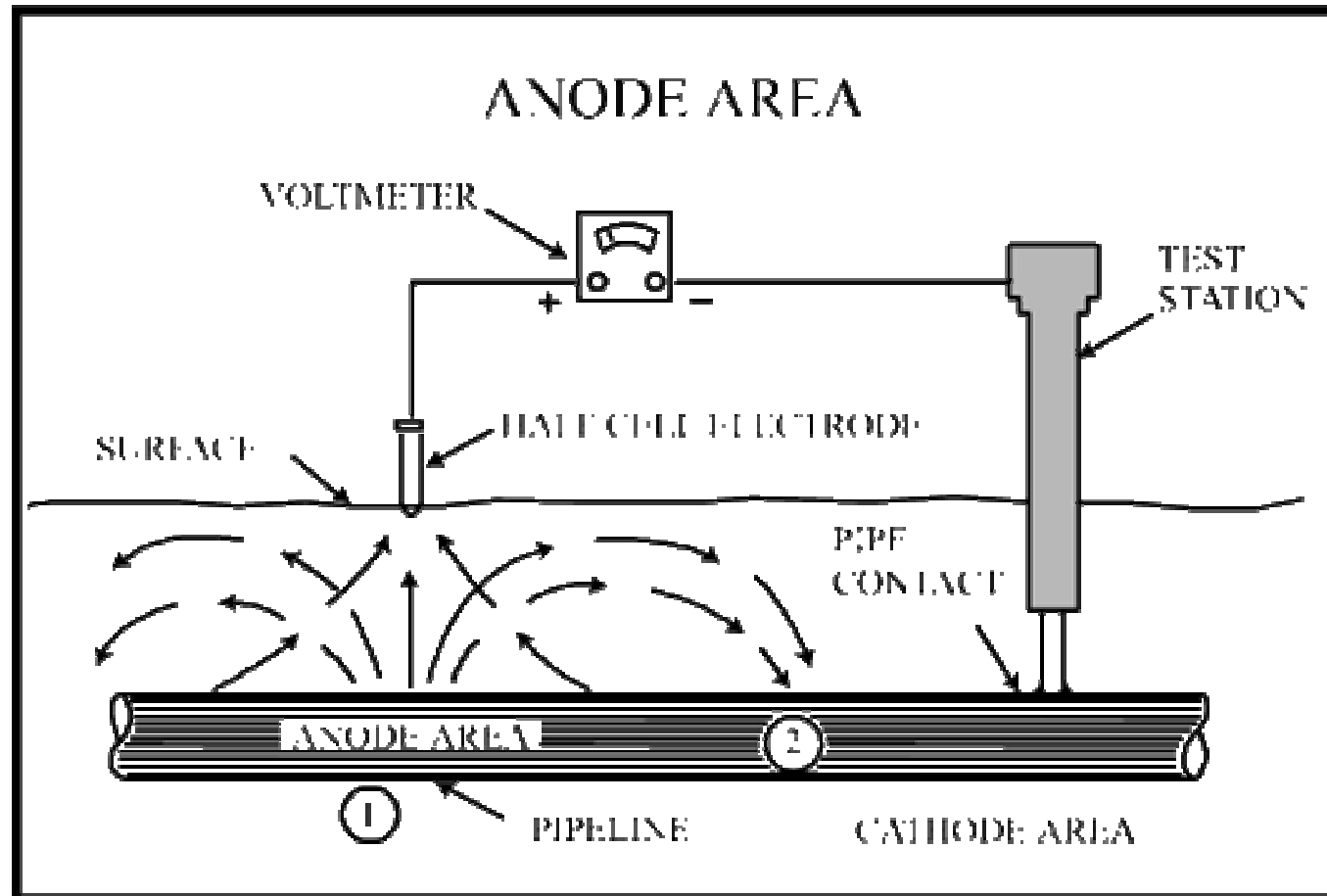
# UNDERGROUND METALLIC PIPING SYSTEM FOR PROTECTION



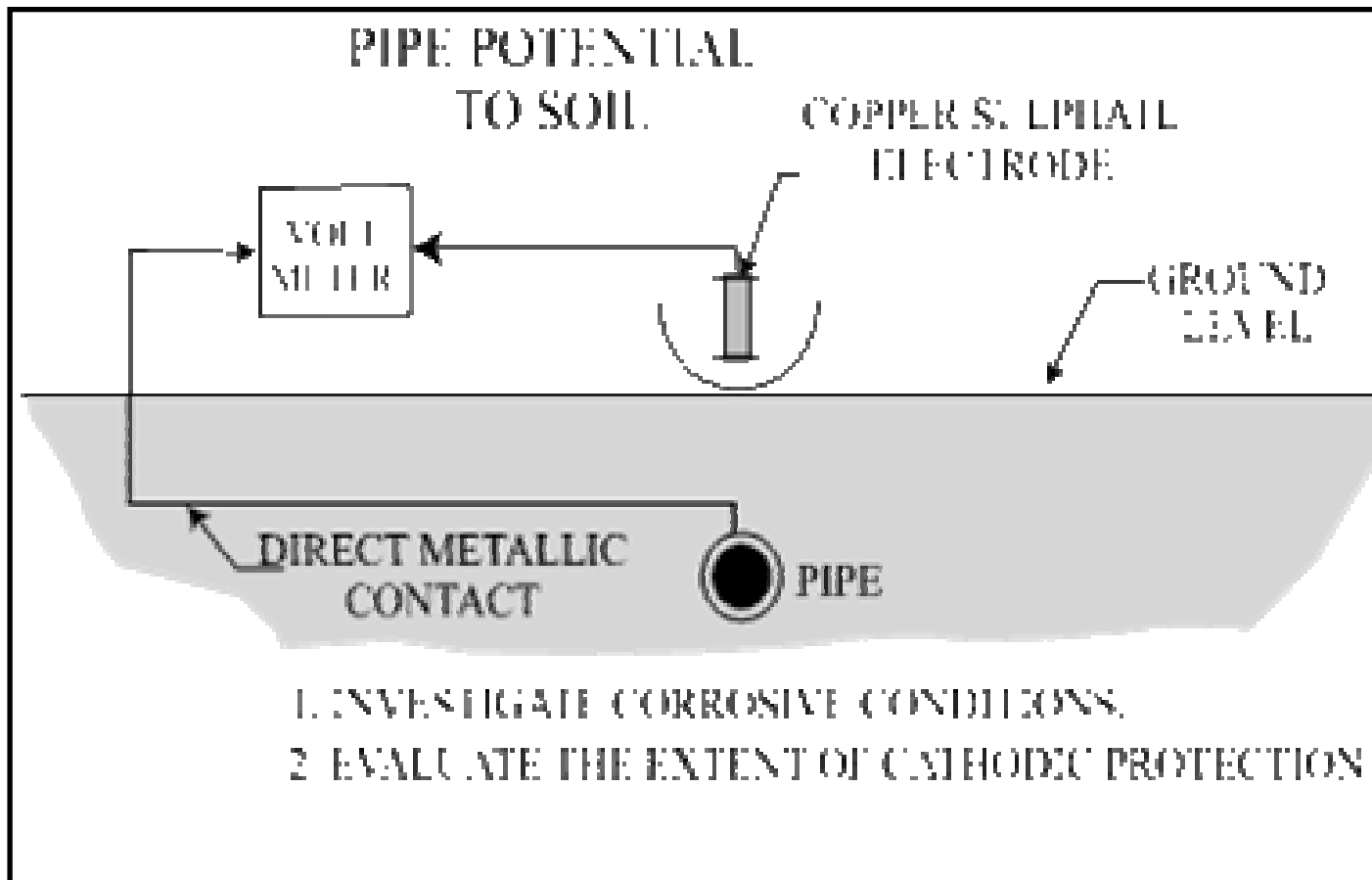
# BASIC TERMS

- **Rectifier** is an electrical device that changes alternating current (a.c.) into direct current (d.c.). This current is then impressed on an underground metallic piping system to protect it against corrosion
- **Potential** means the difference in voltage between two points of measurement
- **Pipe-to-soil potential** is the potential difference (voltage reading) between a buried metallic structure (piping system) and the soil surface.
- **Reference electrode (commonly called a half-cell)** is a device which usually has copper immersed in a copper sulphate solution.

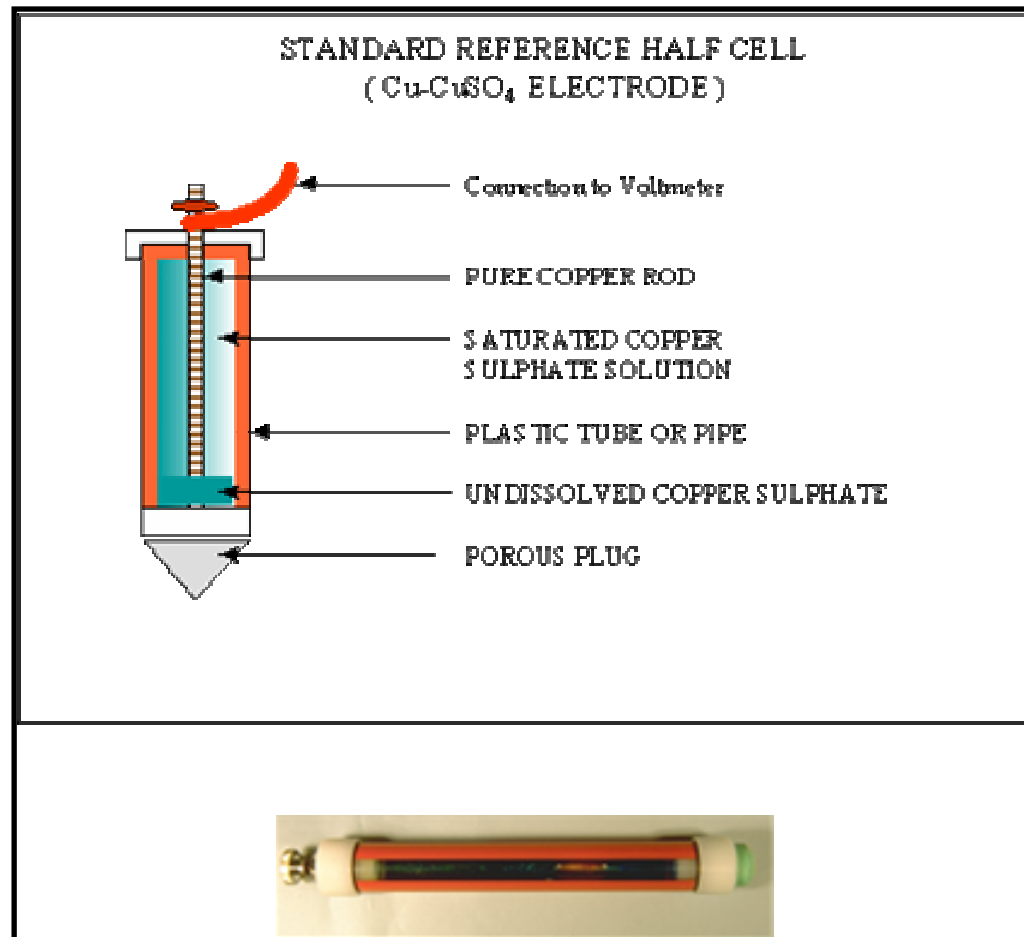
# MEANS OF POTENTIAL



# PIPE TO SOIL POTENTIAL



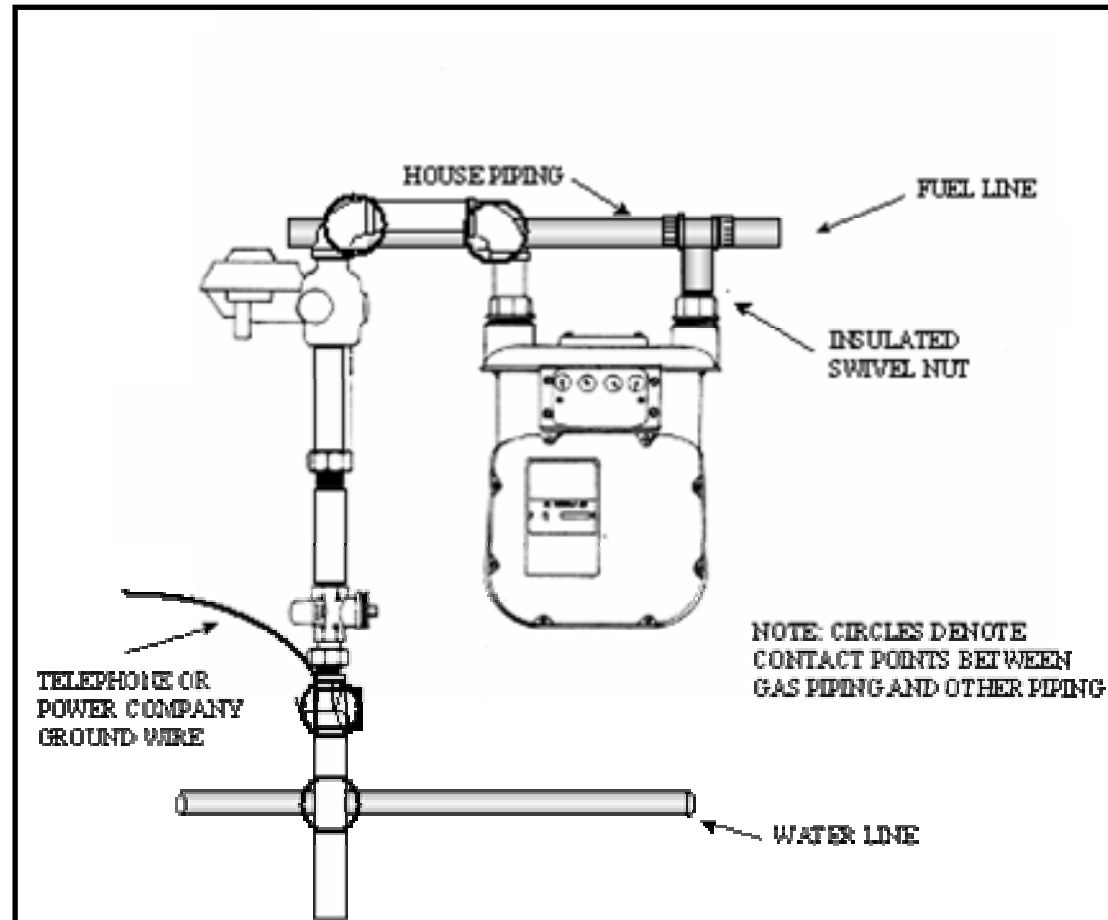
# REFERENCE ELECTRODE



# BASIC TERMS

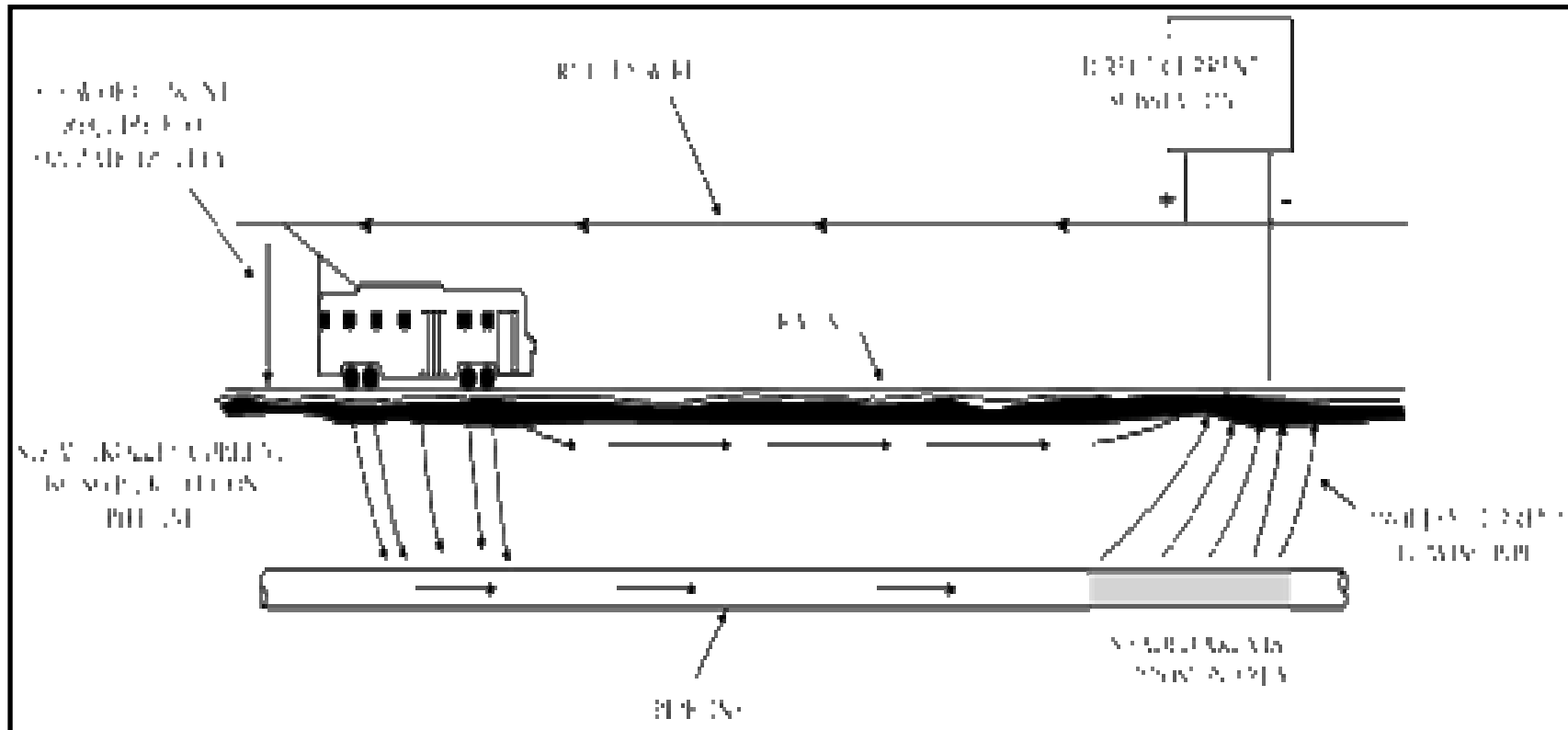
- **Short** or **corrosion fault** means an accidental or incidental contact between a cathodically protected section of a piping system and other metallic structures
- **Stray current** means current flowing through paths other than the intended circuit. If your pipe-to-soil readings fluctuate, stray current may be present
- **Stray current corrosion** means metal destruction or deterioration caused primarily by stray D.C. affecting the pipeline.
- **Galvanic series** is a list of metals and alloys arranged according to their relative potentials in a given environment.
- **Galvanic corrosion** occurs when any two of the metals in Table 1 (next page) are connected in an electrolyte (soil). Galvanic corrosion is caused by the different potentials of the two metals.

# TYPICAL METER INSTALLATION ACCIDENTAL CONTACT





# STRAY CURRENT

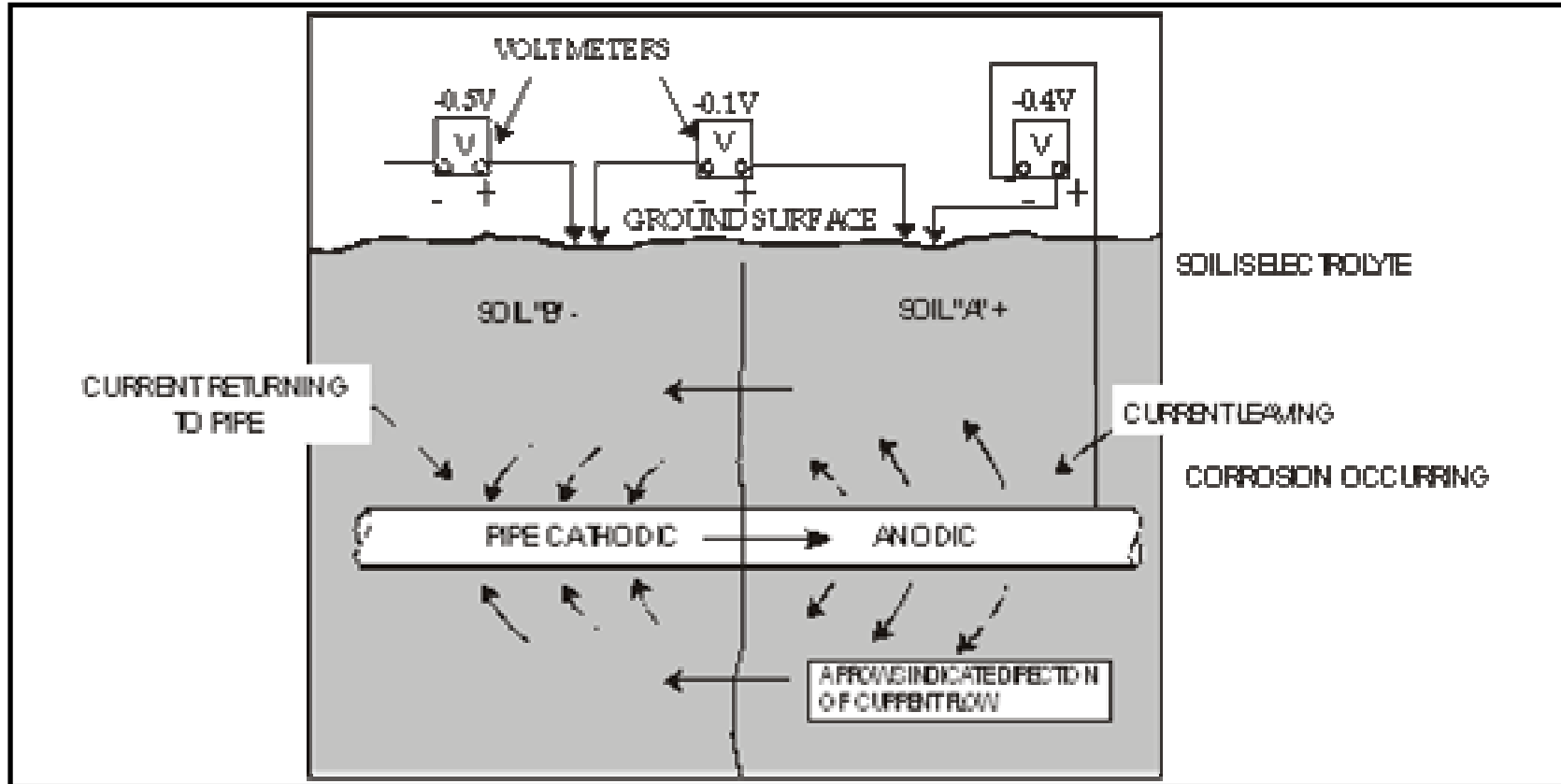


# GALVANIC POTENTIAL OF METALS

<u>METAL</u>	<u>Potentials</u> <u>VOLTS*</u>	
Commercially pure magnesium	-1.75	Anodic ↑ ↓ Cathodic
Magnesium alloy (6% Al, 3% Zn, 0.15% Mn)	-1.6	
Zinc	-1.1	
Aluminum alloy (5% zinc)	-1.05	
Commercially pure aluminum	-0.8	
Mild steel (clean and shiny)	-0.5 to -0.8	
Mild steel (rusted)	-0.2 to -0.5	
Cast iron (not graphitized)	-0.5	
Lead	-0.5	
Mild steel in concrete	-0.2	
Copper, brass, bronze	-0.2	
High silicon cast iron	-0.2	
Mill scale on steel	-0.2	
Carbon, graphite, coke	+0.3	
Cathodic		

\* Typical potential in natural soils and water, measured with respect to a copper-copper sulphate reference electrode

# FUNDAMENTAL CORROSION THEORY



# FUNDAMENTAL CORROSION THEORY

## A corrosion cell may be described as follows:

- Current flows through the electrolyte from the anode to the cathode. It returns to the anode through the return circuit.
- Corrosion occurs whenever current leaves the metal and enters the soil. The area where current leaves is said to be anodic. Corrosion, therefore, occurs in the anodic area.
- Current is picked up at the cathode. No corrosion occurs here. The cathode is protected against corrosion. Polarization (hydrogen film buildup) occurs at the cathode. When the film of hydrogen remains on the cathode surface, it acts as an insulator and reduces the corrosion current flow.
- The flow of current is caused by a potential (voltage) difference between the anode and the cathode.

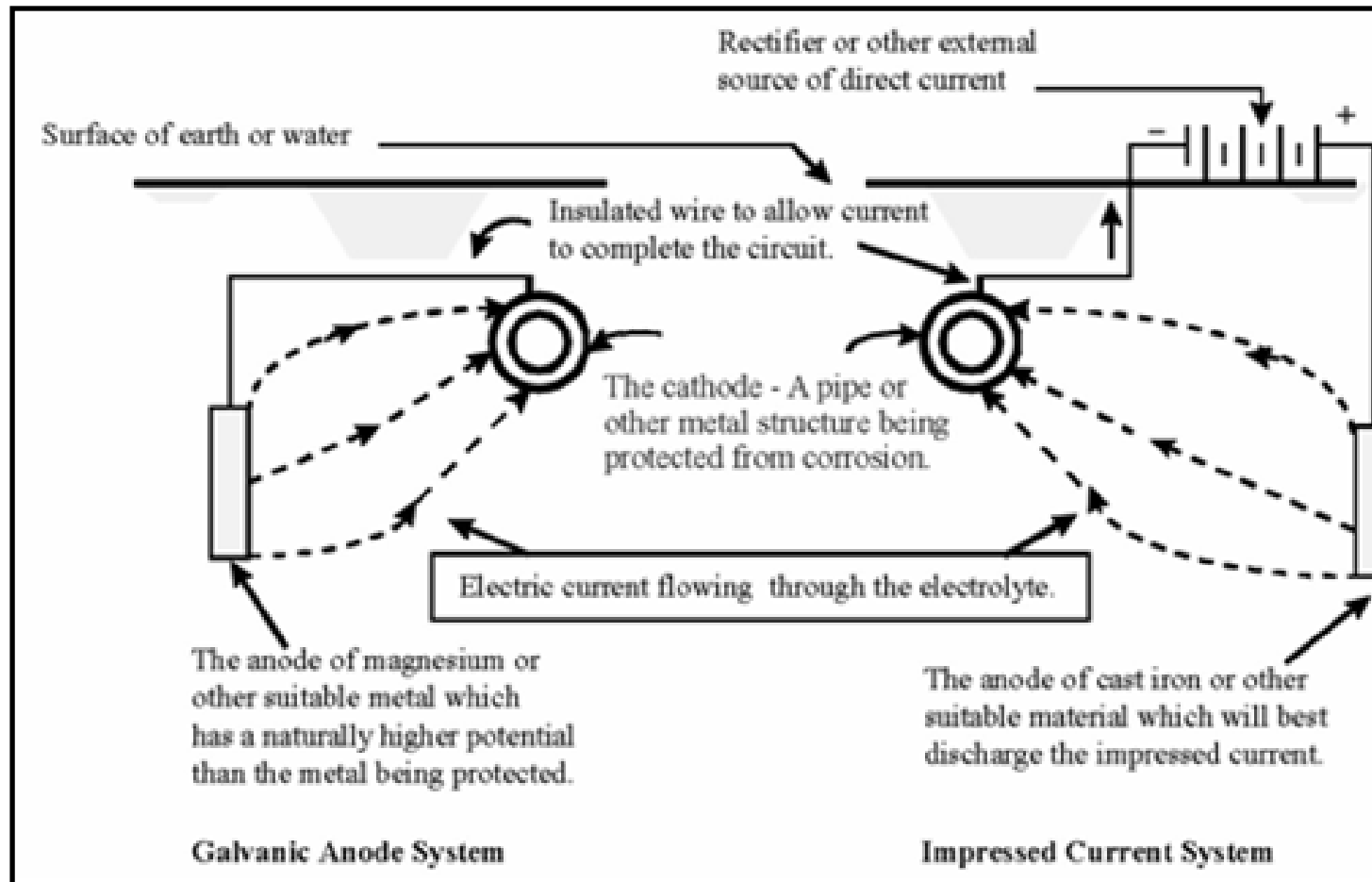
# TYPES OF CATHODIC PROTECTION

- Galvanic Anode System.
  - Anodes are "sized" to meet current requirements of the resistivity of the environment (soil).
  - The surface area of the buried steel and estimated anode life determines the size and number of anodes required.
  - Anodes are made of materials such as magnesium (Mg), zinc (Zn), or aluminum (Al).
  - They are usually installed near the pipe and connected to the pipe with an insulated conductor.

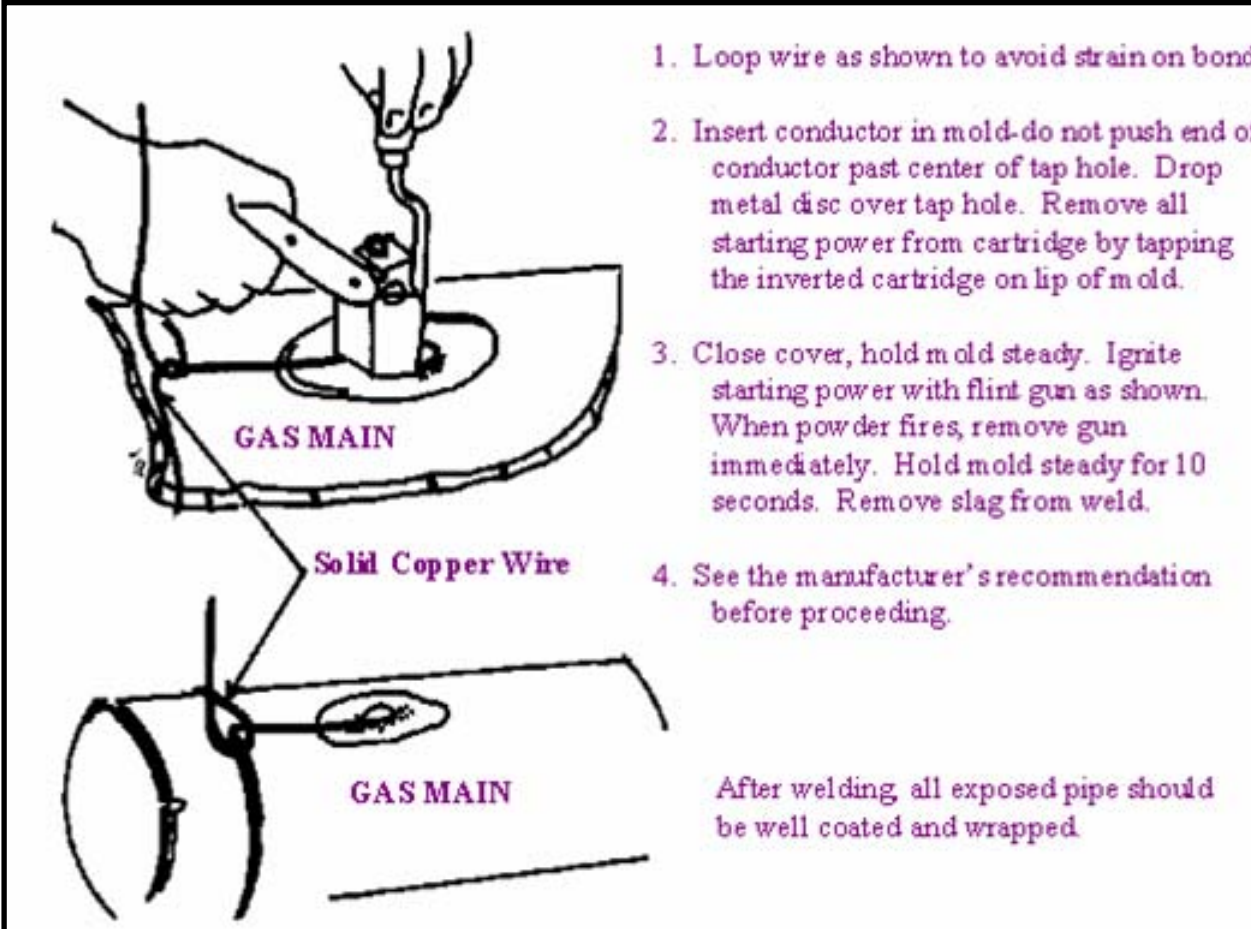
# TYPES OF CATHODIC PROTECTION

- Impressed Current Systems.
  - Anodes are connected to a direct current source, such as a rectifier or generator.
  - These systems are normally used along transmission pipelines where there is less likelihood of interference with other pipelines.
  - The principle is the same except that the anodes are made of materials such as graphite, high silicon cast iron, lead-silver alloy, platinum, or scrap steel.

# GALVANIC ANODE SYSTEM



# IMPRESSED CURRENT SYSTEMS



1. Loop wire as shown to avoid strain on bond.

2. Insert conductor in mold-do not push end of conductor past center of tap hole. Drop metal disc over tap hole. Remove all starting power from cartridge by tapping the inverted cartridge on lip of mold.

3. Close cover, hold mold steady. Ignite starting power with flint gun as shown. When powder fires, remove gun immediately. Hold mold steady for 10 seconds. Remove slag from weld.

4. See the manufacturer's recommendation before proceeding.

After welding all exposed pipe should be well coated and wrapped.

GAS MAIN

Solid Copper Wire

GAS MAIN



# Determining the Need to Cathodically Protect Gas Distribution System

1. Determine type(s) of pipe in system: bare steel, coated steel, cast iron, plastic, galvanized steel, ductile iron, or other.
2. Date gas system was installed:
  - Year pipe was installed (steel pipe installed after July 1, 1971, must be cathodically protected in its entirety).
  - Who installed pipe? By contacting the contractor and other operators who had pipe installed by same contractor, operators may be able to obtain valuable information, such as:
    - Type of pipe in ground.
    - If pipe is electrically isolated.
    - If gas pipe is in common trench with other utilities.

# Determining the Need to Cathodically Protect Gas Distribution System

3. Pipe location - map/drawing. Locate old construction drawings or current system maps. If drawings are unavailable, a metallic pipe locator may be used.
4. Before the corrosion engineer arrives, it is a good idea to make sure that customer meters are electrically insulated. If system has no meter, check to see if gas pipe is electrically insulated from house or mobile home pipe
5. Contact an experienced corrosion engineer or consulting firm. Try to complete steps 1 through 4 before contracting a consultant.

# Determining the Need to Cathodically Protect Gas Distribution System

3. Use of Consultant: A sample method, which may be used by a consultant to determine cathodic protection needs, is provided below:
  - An initial pipe-to-soil reading will be taken to determine whether the system is under cathodic protection.
  - If the system is not under cathodic protection, the consultant should clear underground shorts or any missed meter shorts. (The consultant will probably use a tone test.)
  - After the shorts are cleared, another pipe-to-soil test should be taken. If the system is not under cathodic protection, a current requirement test should be run to determine how much electrical current is needed to protect the system.

# Determining the Need to Cathodically Protect Gas Distribution System

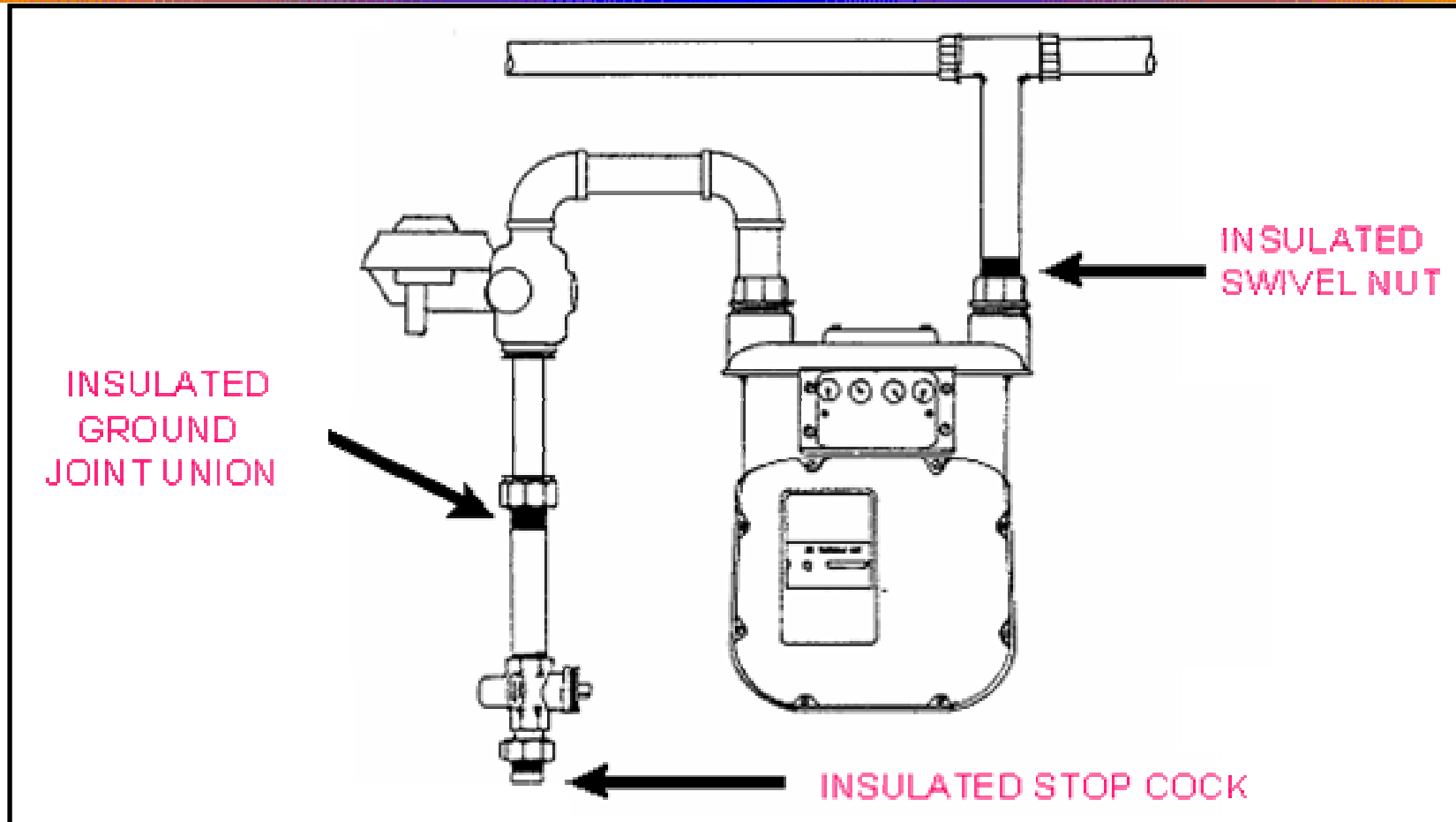
- Additional tests, such as a soil resistivity test, bar hole examination, and other electrical tests, may be needed. The types of tests needed will vary for each gas system.

Remember to retain copies of all tests run by the corrosion engineer.

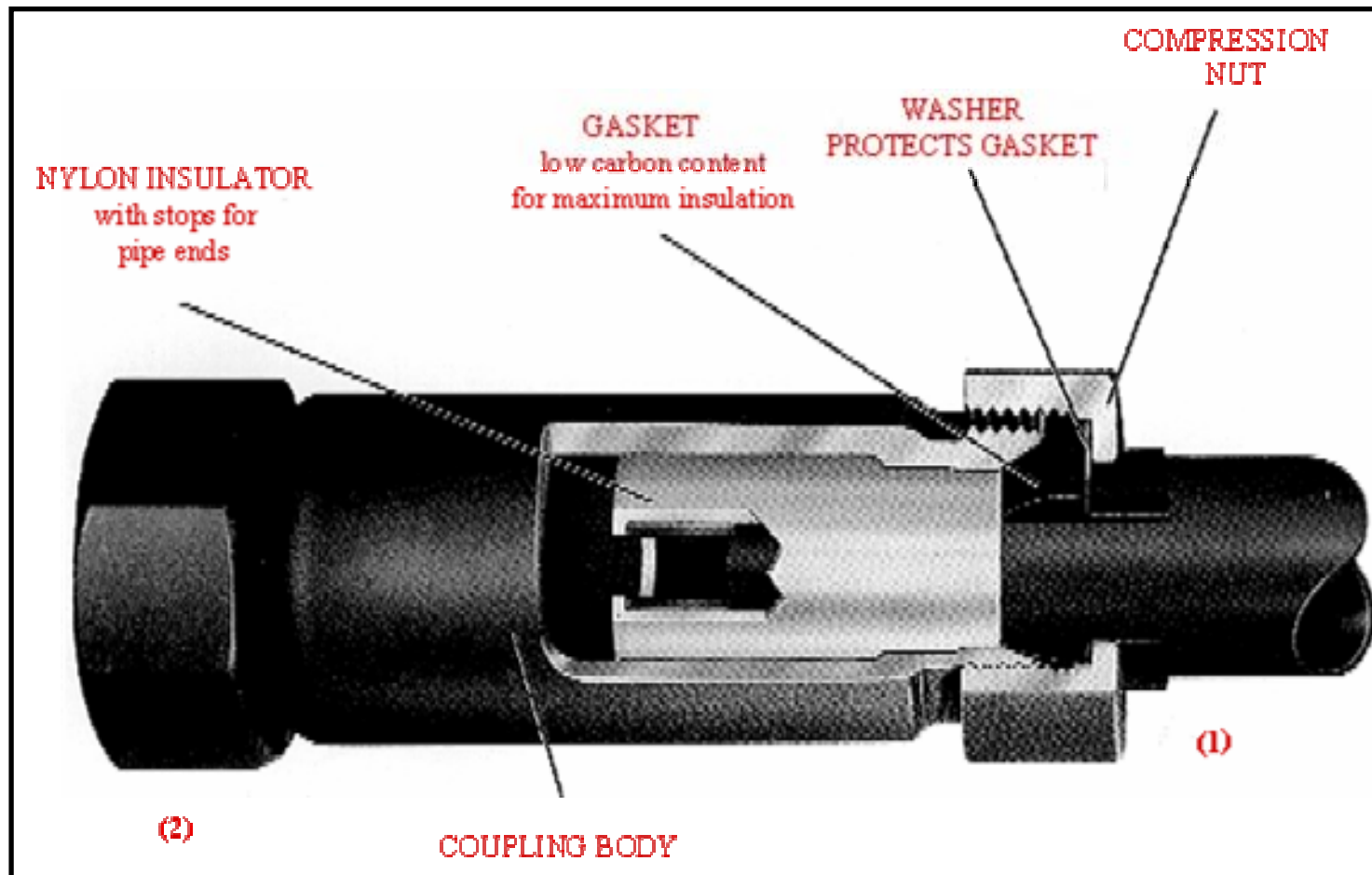
## 7. Cathodic Protection Design

- The experienced corrosion engineer or gas consultant, will design a cathodic protection system based on the results of testing, that best suits the gas piping system.

# METER INSTALLATION ELECTRICALLY ISOLATED



# AN INSULATED COMPRESSION COUPLING



# INSULATION TESTER

- Insulation tester consists of a magnetic transducer mounted in a single earphone headset with connecting needlepoint contact probes.
- It is a "go" or "no go" type tester which operates from low voltage current present on all underground piping systems thus eliminating the necessity of outside power sources or costly instrumentation and complex connections.
- By placing the test probes on the metallic surface on either side of the insulator a distinct audible tone will be heard if the insulator is performing properly.
- Absence of audible tone indicates faulty insulator.
- Insulator effectiveness can be determined quickly using this simple, easy-to-operate tester.

# INSULATION TESTER



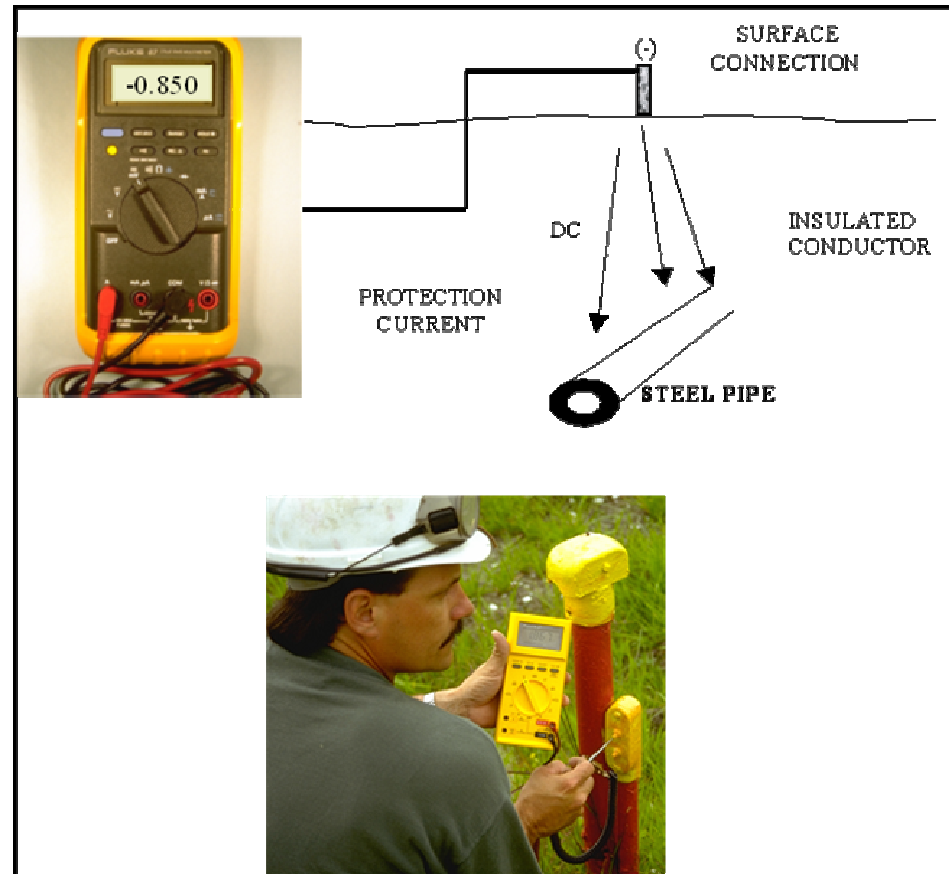


# CRITERIA FOR CATHODIC PROTECTION

- With the protective current applied, a voltage of at least -0.85 volt measured between the pipeline and a saturated copper-copper sulfate half-cell.
- **Coatings**
- **Mill Coated Pipe**
- **Patching**

# CRITERIA 1

- With the protective current applied, a voltage of at least -0.85 volt measured between the pipeline and a saturated copper-copper sulfate half-cell.
- This measurement is called the pipe-to-soil potential reading



# COATINGS

- Many different types of coating on the market.
- The better the coating application, the less electrical current is needed to cathodically protect the pipe

## Mill Coated Pipe

- When purchasing steel pipe for underground gas services, operators should purchase mill coated pipe (i.e., pipe coated during manufacturing process).
- Some examples of mill coatings are:
  - Extruded polyethylene or polypropylene plastic coatings,
  - Coal tar coatings,
  - Enamels,
  - Mastics,
  - Epoxy.

# PATCHING

- Tape material is a good choice for external repair of mill coated pipe.
- Tape material is also a good coating for both welded and mechanical joints made in the field.
- Some tapes in use today are:
  - PE and PVC tapes with self-adhesive backing applied to a primed pipe surface,
  - Plastic films with butyl rubber backing applied to a primed surface,
  - Plastic films with various bituminous backings.

# COATING APPLICATION PROCEDURES

- Properly clean pipe surface (remove soil, oil, grease, and any moisture),
- Use careful priming techniques (avoid moisture, follow manufacturer's recommendations),
- Properly apply the coating materials (be sure pipe surface is dry - follow manufacturer's recommendations). Make sure soil or other foreign material does not get under coating during installation,
- Only backfill with material that is free of objects capable of damaging the coating. Severe coating damage can be caused by careless backfilling when rocks and debris strike and break the coating.

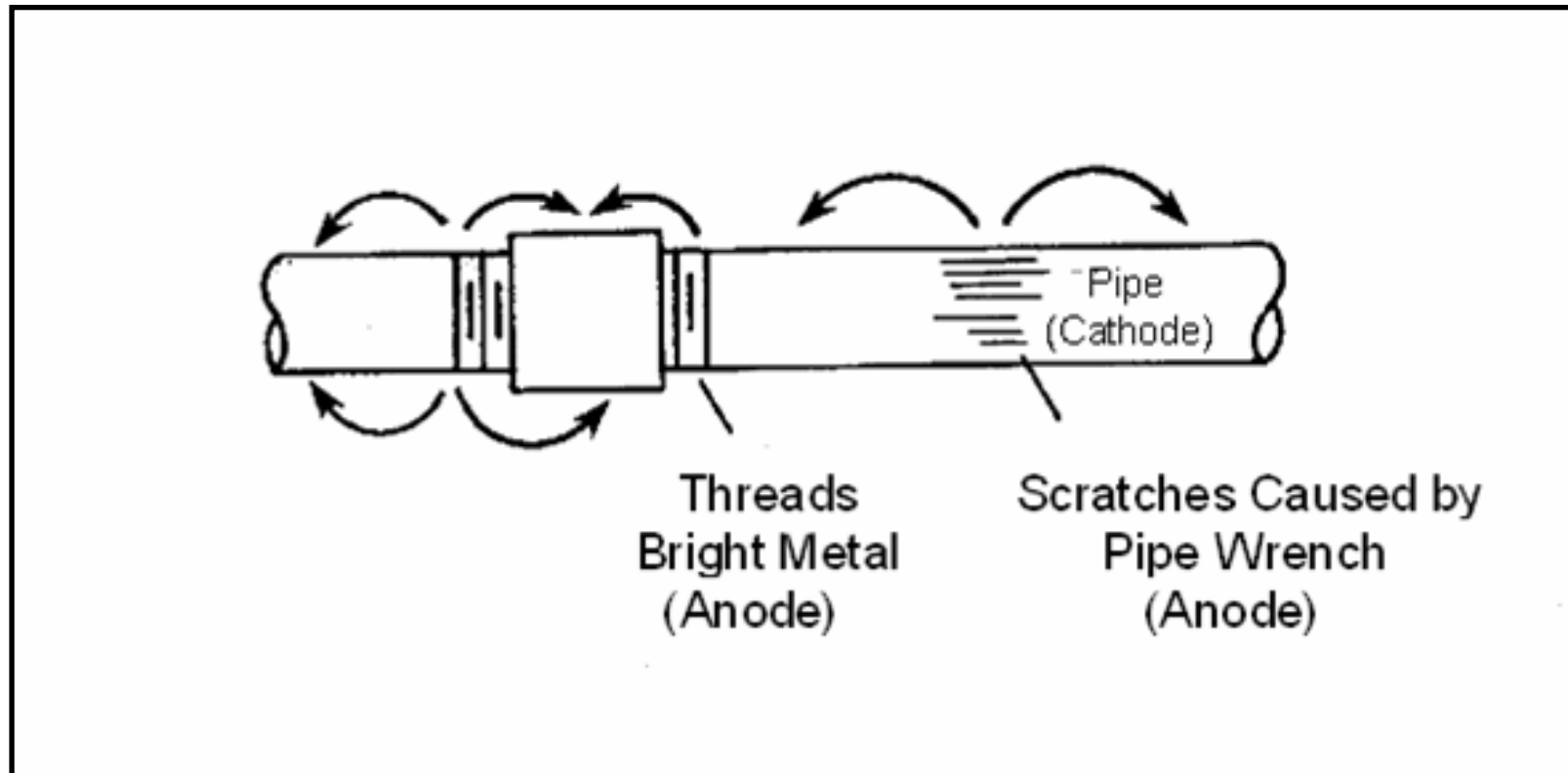
# CAUSES OF CORROSION

## (Shorted meter set)

- The tenants of this building have "shorted" out this meter by storing metallic objects on the meter set.
- Never allow customers or tenants to store material on or near a meter installation.

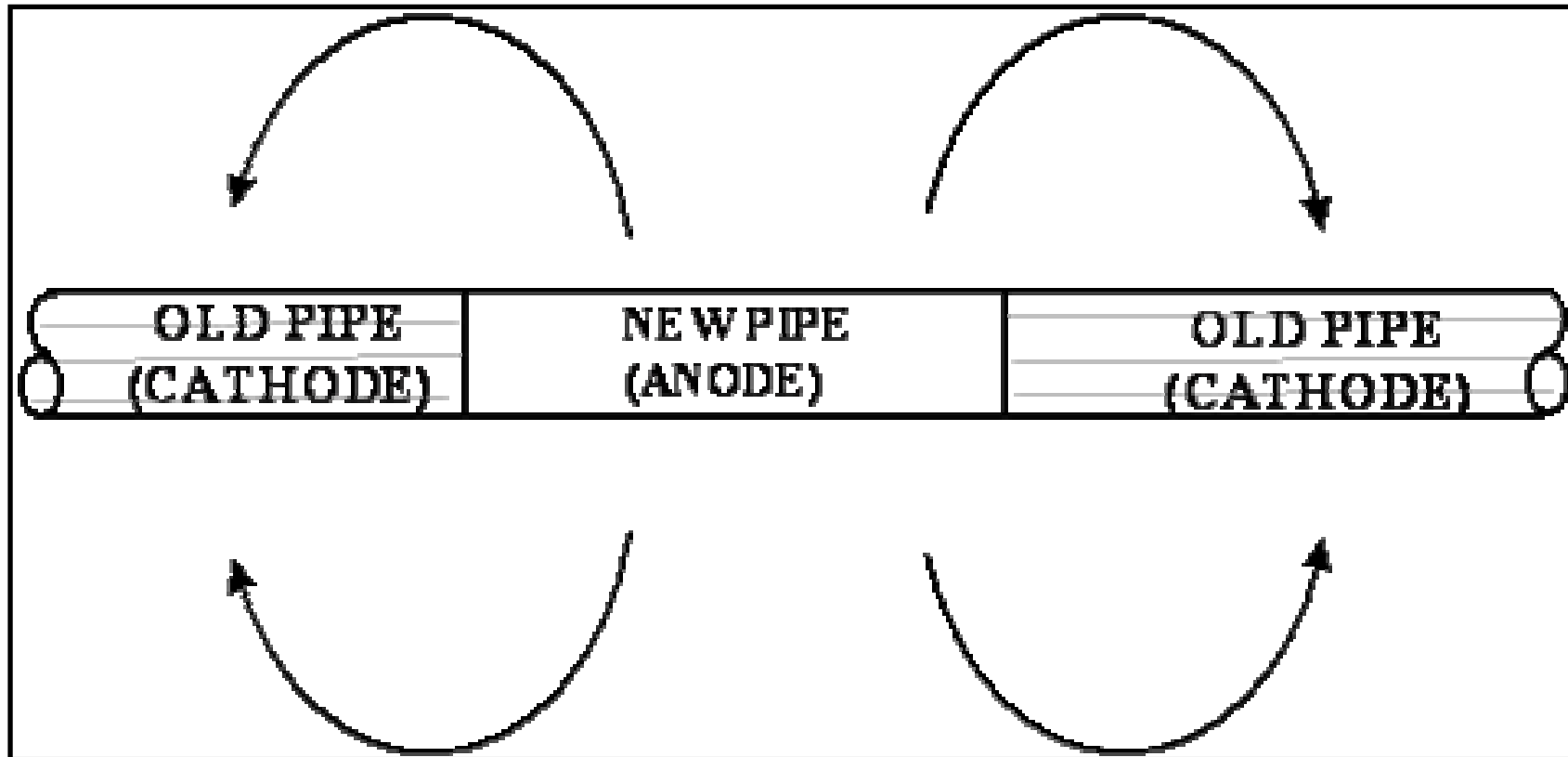


# CAUSES OF CORROSION (dissimilar surface conditions)



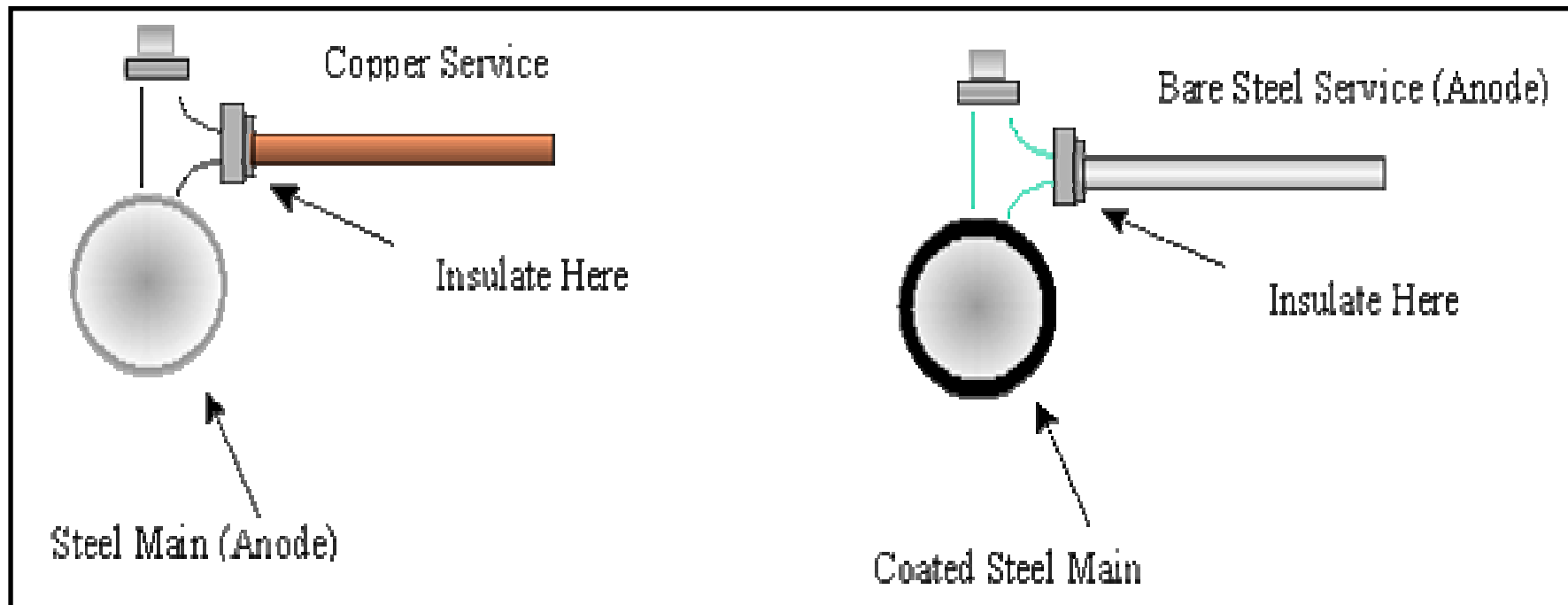
# CAUSES OF CORROSION

## (Galvanic corrosion )



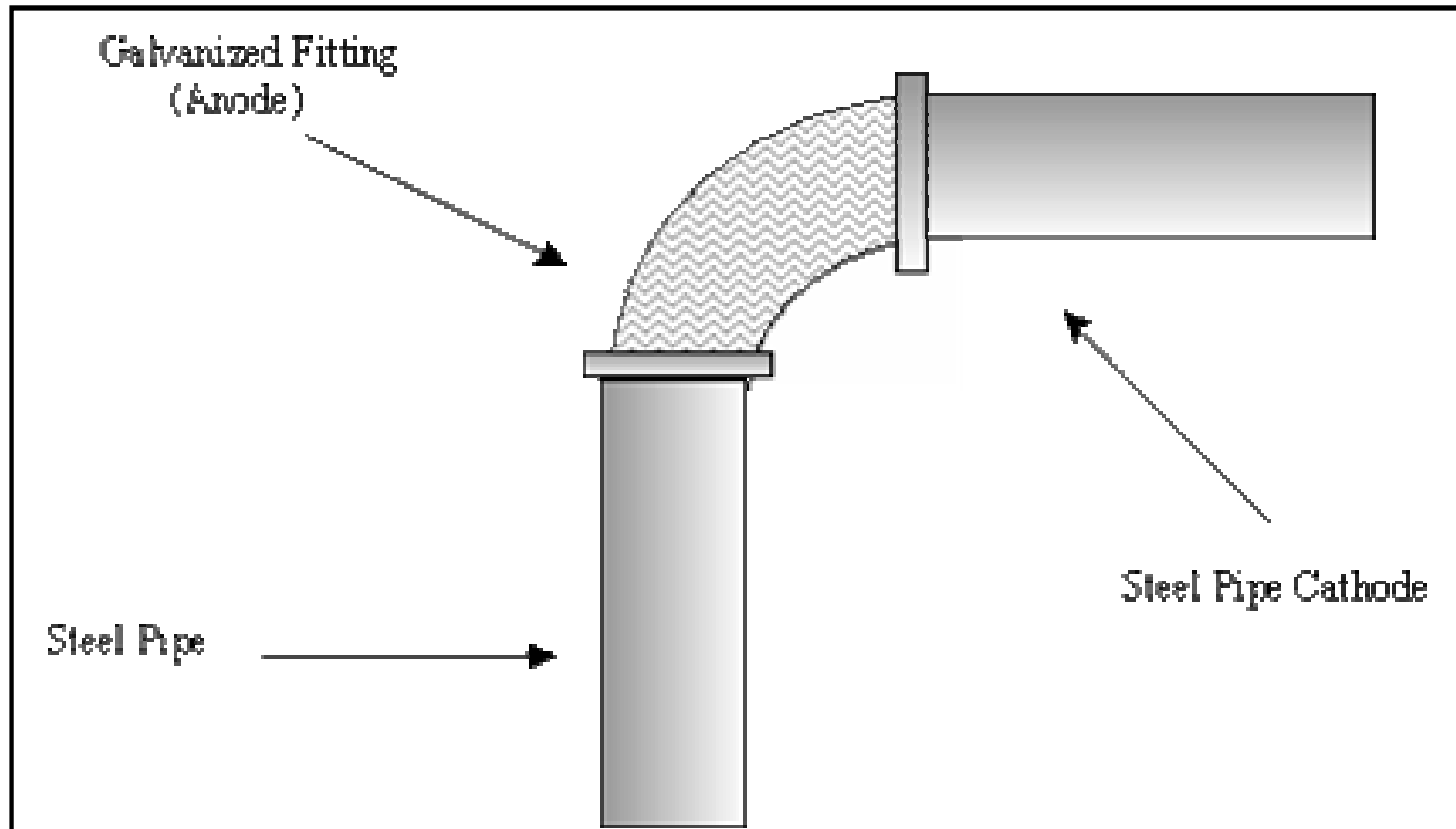


# CAUSES OF CORROSION (Galvanic corrosion )



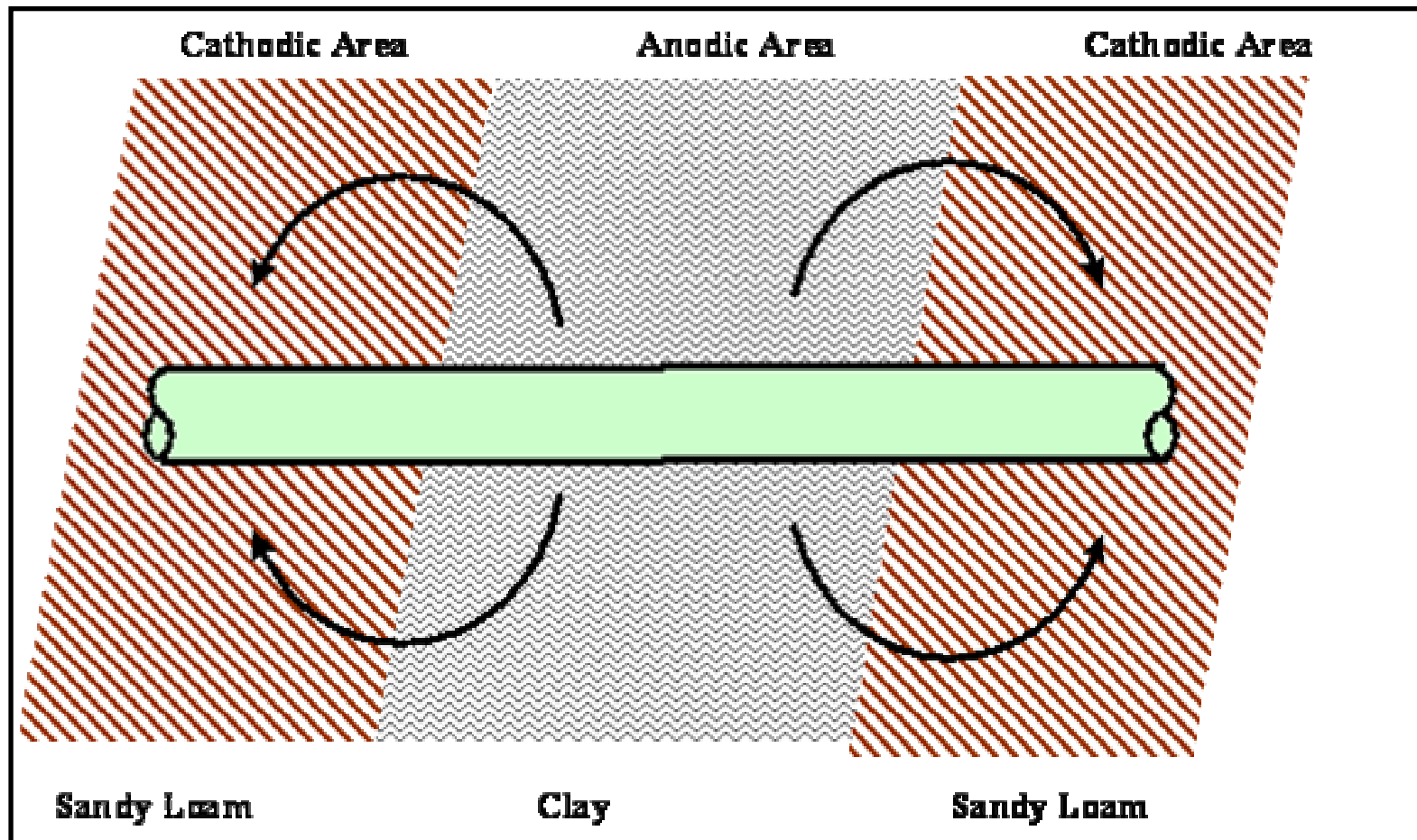
# CAUSES OF CORROSION

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# CAUSES OF CORROSION

## (Galvanic corrosion )

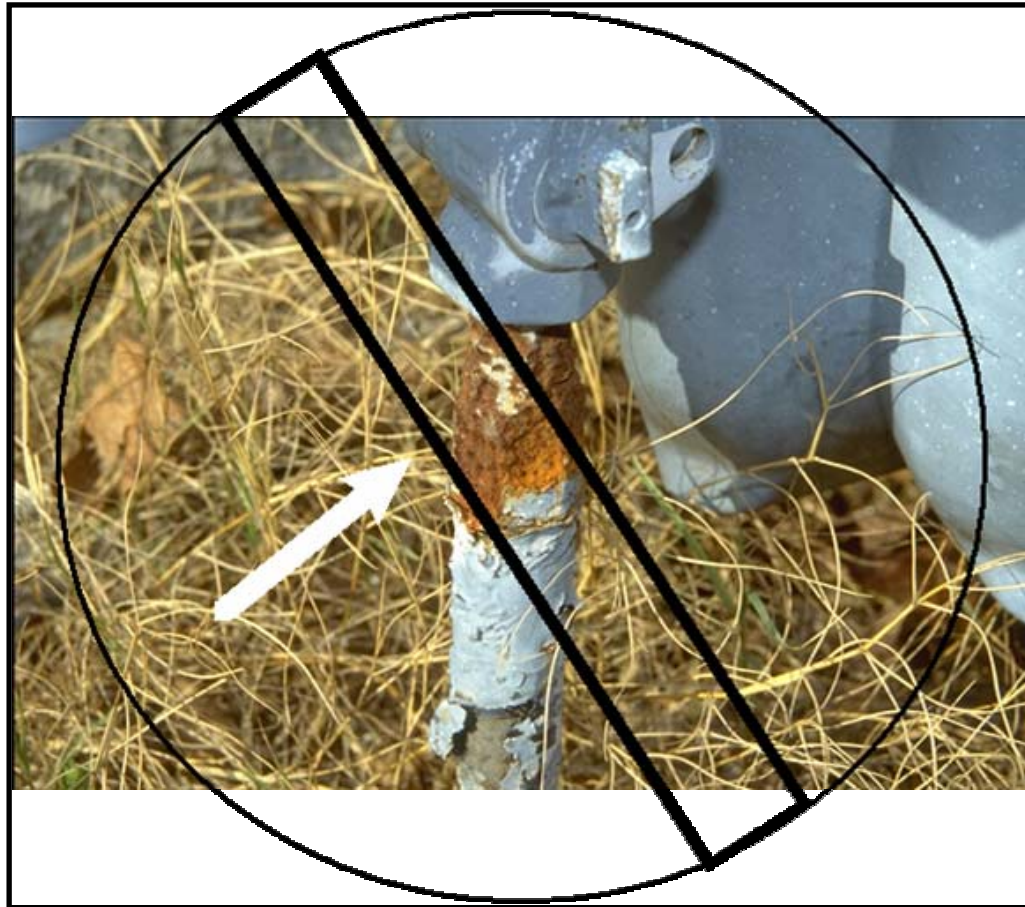


# CAUSES OF CORROSION (Poor construction practice )



# CAUSES OF CORROSION

## (Atmospheric corrosion)



# PIPELINE STRESS CORROSION CRACKING (SCC)

- Over 98% of pipelines are buried
- They are subjected to environmental abuse, external damage, coating disbandment, inherent mill defects, soil movements/instability and third party damage
- This occurs due to a combination of appropriate environment, stresses (absolute hoop and/or tensile, fluctuating stress) and material (steel type, amount of inclusions, surface roughness.)
- Environment is a critical causal factor in SCC. High-pH SCC failures of underground pipelines have occurred in a wide variety of soils, covering a range in color, texture, and pH
- No single characteristic has been found to be common to all of the soil samples

# PIPELINE STRESS CORROSION CRACKING (SCC)

- No consistency of water with the physical descriptions of the soils
- Small quantities of electrolytes obtained from beneath disbonded coatings near locations where stress corrosion cracks were detected
- The components of the electrolytes were carbonate and bicarbonate ions
- It is recognized that a concentrated carbonate-bicarbonate environment is responsible for the formation of cracking
- Anions present in the soils and electrolytes, in addition to an appropriate coating failure, the local soil, temperature, water availability, and bacterial activity have a critical impact on SCC susceptibility

# SCC PROPENSITY

- There are two types of SCC normally found on pipelines: high pH (9 to 13) and near-neutral pH SCC (5 to 7)
- The high pH SCC caused numerous failures in USA in the early 1960's and 1970's
- The near-neutral pH SCC failures were recorded in Canada during the mid 1980's to early 1990's.
- The SCC failures have continued throughout the world including Australia, Russia, Saudi Arabia, South America and other parts of the world
- High pH SCC - This is a classical SCC, which was originally noted in gas transmission pipelines. It is normally found within 20 kilometers downstream of the compressor station



# SCC PROPENSITY

- High pH SCC normally occurs in a relatively narrow cathodic potential range (-600 to -750 mV Cu/CuSO<sub>4</sub>) in the presence of a carbonate/bicarbonate environment in a pH window from 9 to 13.
- Temperatures greater than 40 °C are necessary for high pH SCC susceptibility, growth rates decrease exponentially with temperature
- Intergranular cracking mode generally represents high pH SCC
- A thin oxide layer is formed in the concentrated carbonate-bicarbonate environment, which around the crack surfaces provides protection.
- Due to changes in loading or cyclic loading, a crack tip strain resulting in breakage of oxide film, results in crack extension due to corrosion.
- Because of such a stringent environmental requirement for SCC initiation, this is not as prevalent as the near-neutral pH SCC.
- This type of SCC has been primarily noted in gas transmission lines (temperature.)

# HIGH pH SCC INTEGRITY MANAGEMENT STRATEGY

- Evaluate and establish extent of SCC susceptibility.
- Ensure that the material, coating and other operational conditions are conducive for SCC.
- Utilize over the ditch coatings survey to identify locations of holiday & match them with high stress levels (60% specified minimum yield strength (SMYS))
- Additionally match it with high temperature locations.
- Finally if there is an inspection run match the corrosion locations with coating failure if these exist; especially with minor corrosion.
- Excavate to identify susceptibility (should also be conducted as part of due diligence during corrosion management.)

# IF SCC SUSCEPTIBLE

- Quantify life cycle of the pipeline; conduct fracture mechanics calculations to estimate where in the system an SCC rupture is likely using excavation results.
- Utilizing this as a basis, a next step involves further evaluation of the degree of SCC.
- (In-line inspection) or hydrostatic test may be warranted.
- If inspection tools don't exist (diameter or pigability) an appropriately defined hydrostatic test program may be effective.
- If inspection tool options are viable; circumferential MFL tools may be a screening option, depending on crack opening; or ultrasonic tools may be a more permanent option as a true alternative to hydrostatic testing.
- Longer term mitigation will have to include temperature reduction (if possible.)

# IF SCC NOT SUSCEPTIBLE

- Continue monitoring for SCC while managing integrity for other issues such as corrosion.

# NEAR-NEUTRAL pH SCC

- Initially noted in Canada, and has been observed by operators in the US
- Diluted groundwater containing dissolved CO<sub>2</sub> is responsible
- The CO<sub>2</sub> originates (like in high pH) from the decay of organic matter.
- Cracking is further exacerbated by the presence of sulfate reducing bacteria.
- This occurs due to disbanded coatings, which shields the cathodic current that could reach the pipe surface.

# NEAR-NEUTRAL pH SCC MANAGEMENT

- Evaluate and establish extent of SCC susceptibility – ensure the material and coating parameters indicate susceptibility to SCC.
- Utilize corrosion inspection survey to identify areas of corrosion linearity or small pitting corrosion locations to identify sites for SCC susceptibility.
- Identify locations of high cyclical pressure combined with a high operating pressure.
- Excavate at many of these locations to develop extent of SCC on the pipeline system.
- Additional parameters such as soil and drainage can be considered for SCC susceptibility, but should be used with caution. For example, both very poor and well drained soils have shown susceptibility to SCC.

# IF SCC SUSCEPTIBLE

- Utilizing this as a basis, identify the time period available for mitigating the problem. If the time period is small, then hydrostatic testing may represent the best short term approach to this problem.
- If the time period available is high or there is no immediate danger ( $< 1$  year) to the pipeline, then options such as inline inspection can be considered.
- The circumferential MFL is a good screening tool for SCC, but the ultrasonic shear wave tools are highly reliable for SCC.
- A regular inspection and rehabilitation may prove to be a long term solution to managing SCC.
- If no inspection option is available, then the regular hydrostatic testing is the only option to mitigate failure from SCC.

# IF SCC NOT SUSCEPTIBLE

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- Continue to monitor and validate the conclusion as part of an overall integrity management program.