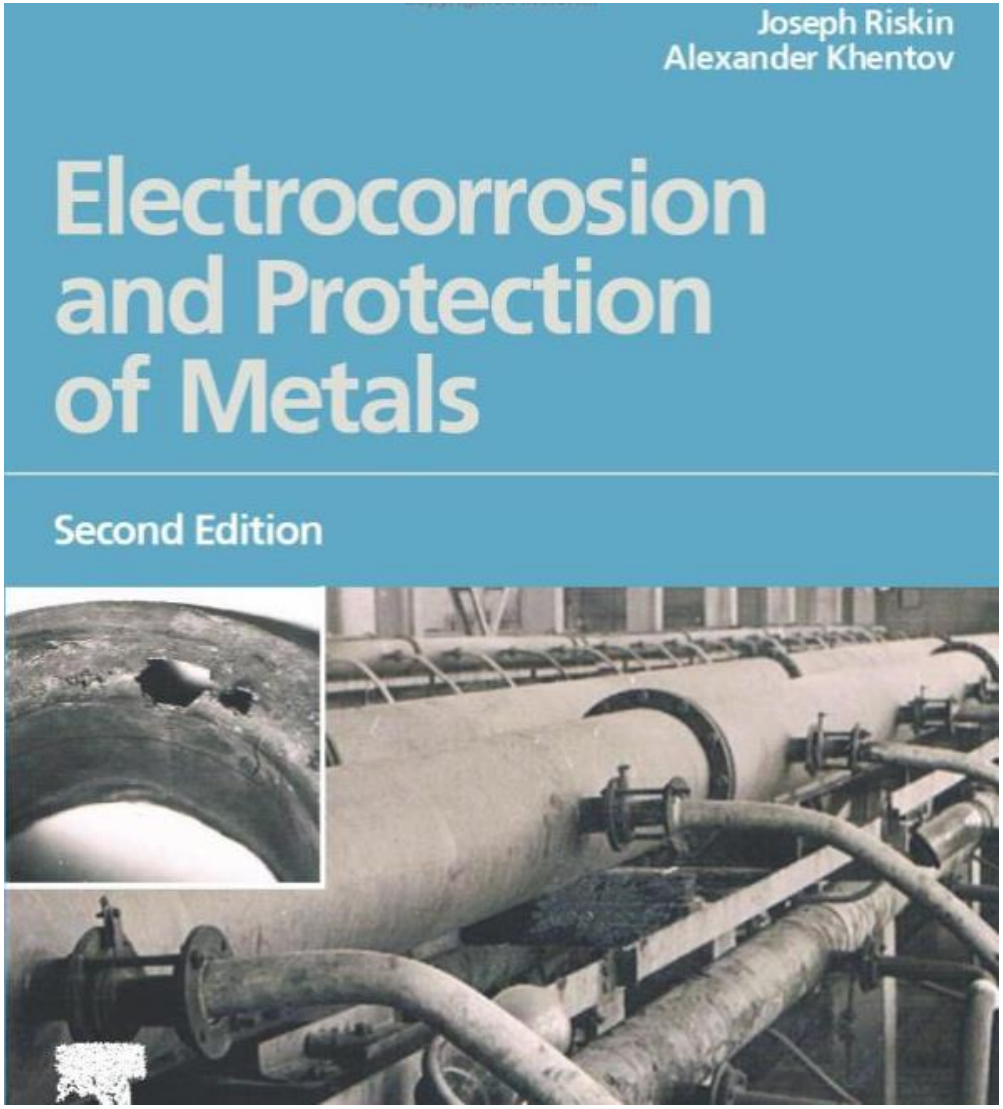
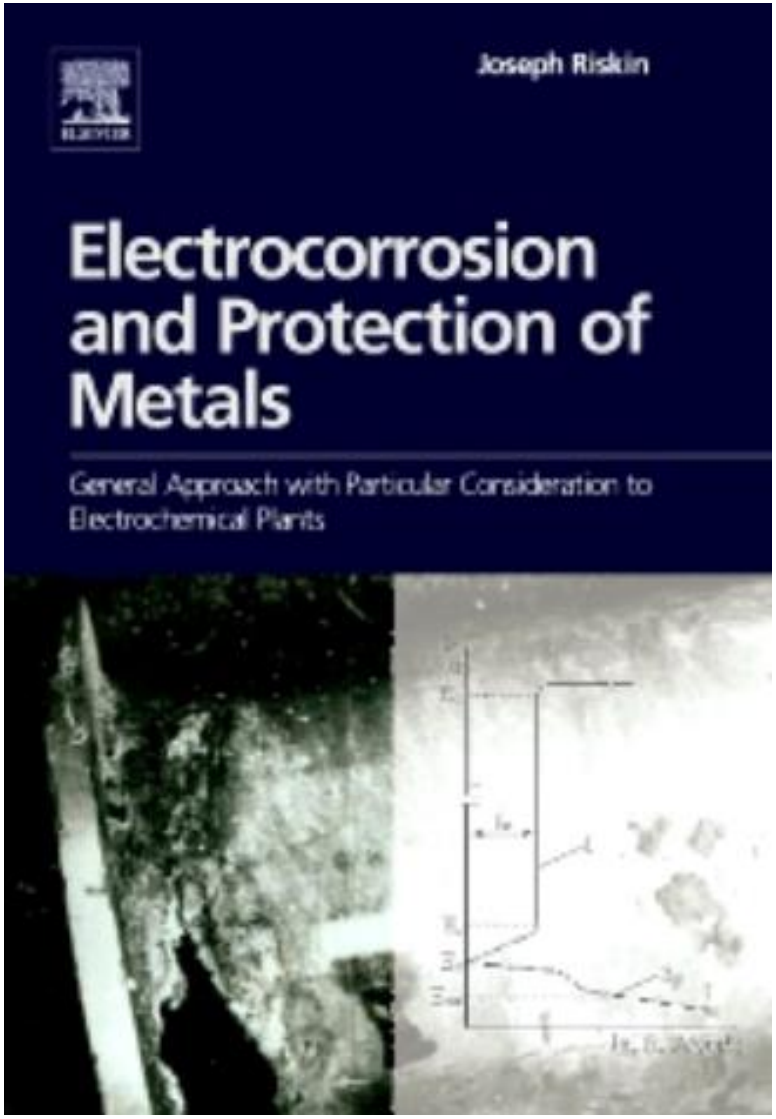



**General Approach with Particular Consideration to Electrochemical Plants**

***(Presentation in 2009 at Beit Hamehandes)***

# PART 1: *Corrosion by stray currents and protection methods*

**In Chapter 1, Corrosion basics, the fundamentals of metal corrosion and protection are given and main types of corrosion damages are considered.**

**In Chapters 2 – 6 problems related to corrosion by different kinds of direct stray currents (DC) of anodic (predominantly ) and cathodic directions are considered: sources and objects of stray currents – methods of their detection, identification and estimation – methods of protection from stray current corrosion. Metal state (active, passive, thermodynamically stable) is taken into account when the attack of external current occurs.**

**In Chapter 7 problems related to corrosion by alternating stray currents (AC) are considered.**

# *Publications on stray current corrosion*

**There are sections dedicated to stray current corrosion in most books on metal corrosion. None of the books was up to now entirely dedicated to this problem as the whole.**

**There are a lot of articles on the problems related to the problems related to stray current corrosion.**

**Most popular is the collection of 39 articles, edited by M.J. Szeliga** : "Stray Current Corrosion: The Past, Present, and Future of Rail Transit Systems", NACE International, Houston, TX, 1994, 300p.

**Up to now did not exist any books or monographs on the problems under consideration.**

# *Sources and objects of underground and underwater stray currents*

**Electrified railways** (the most widespread sources of dynamic stray current);

**Equipment of mining operations** (similar to the previous scheme, but deeper under the ground and more aggressive environment);

**Cathodic protection systems** (widespread sources of static stray currents)**;**

**High voltage direct current (HVDC) transmission lines;**

**Welding operations and other electric utilities;**

**Alternative renewable energy sources (solar farms and wind farms** which are usually extended over wide areas**);**

**Parts and utilities of the current sources can themselves undergo corrosion attack by stray and leakage currents which they provide.**

**Natural sources: Telluric currents** (dynamic currents produced by earth magnetic field)**;**

**Lightning** (most probable when pipelines are close to high voltage lines)**.**

# *Objects of underground and underwater stray currents*

**Extended objects of stray currents:**
**Rails,**
**Piping,**
**Cables;**

**Underground and aboveground storage tanks ;**

**Structures of reinforced concrete** (rebar of carbon and stainless steel and of carbon steel with Zn coating are considered);

**Radiators and other parts of vehicle cooling systems.**

# *Detection, identification and estimation of stray currents*

**Stray current corrosion identification without resort to special measurement instruments** (visual inspection, using of probes etc.
First indication – abnormally high corrosion rate at the damaged area);

**Detection and estimation of stray currents by measurements of metal-soil potentials and voltage drop on underground structures:**
**Detection of stray current presence on unprotected structures;**
**Estimation of static stray current values on unprotected pipelines by potential difference measurements;**
**Direct measurements of static stray current along unprotected pipeline;**
**Finding dynamic stray current direction on unprotected pipelines by repeated measurements;**
**Detection of stray currents and their sources on protected pipelines;**
**Detection of well casing stray currents;**
**Detection of telluric currents.**

Identification of dynamic currents is much easier than identification of static currents: potential fluctuations point to the presence of these currents.
However, estimation of dynamic stray currents is more complicated problem.

# *Passive methods of prevention and mitigation of stray current corrosion*

**Considered methods of reducing stray currents from:**

**rails,**
**cathodic protection systems,**
**HVDC transmission lines,**
**welding operations,**
**waterborne ships and boats,**
**reinforced concrete structures.**

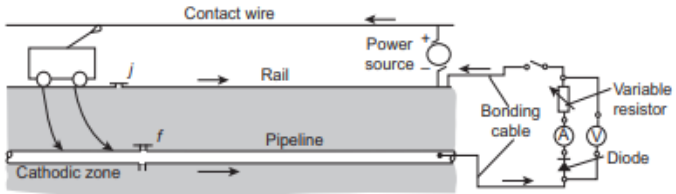
**Mitigation of stray current attack by coating is the most effective passive method of protection.**

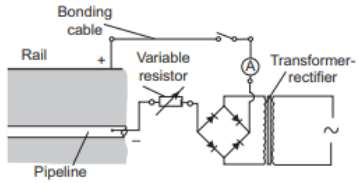
# *Electrical and electrochemical methods of protection from stray current corrosion*

**Protection by electrical drainage bond against stray currents arriving from:**

**- Cathodic protection systems;**

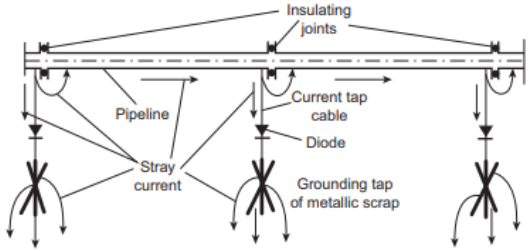
**- Electrical traction systems.**




**Cathodic protection by impressed current in combination with drainage system (forced drainage).**

**Sectionalization of pipelines in combination with other protection methods.**




**Protection from stray current corrosion at the stage of design.**

**Maintenance, control and monitoring in the system of protection from stray current corrosion.**

# *Corrosion by alternating current (AC)*

**Sources of AC;**

**Modes of AC interference: capacitive, conductive and inductive;**

**Likelihood of AC corrosion in soil and in concrete;**

**Mechanism of AC corrosion;**

**AC corrosion and cathodic protection;**

**Identification of AC corrosion;**

**Effect of AC on different metals;**

**Mitigation of AC corrosion:**
**Damage from powerline fault,**
**Consequences of electrostatic and electromagnetic interferences;**

**Monitoring of AC corrosion.**

# PART 2: Corrosion by leakage currents in electrochemical plants and protection methods

# *Major features of the Part 2 which determine the protection methods*

**Electrochemical plants in chemistry:** Water electrolysis for producing hydrogen and oxygen, electrolysis of sodium salts and other chloride solutions for producing chlorine, alkali and oxygen-chlorine compounds, hydrogen peroxide, manganese compounds, persulfates and other peroxides.

**In metallurgy:** Processes of electrolytic refining and extraction of copper, nickel, cobalt, zinc, chromium, metals of platinum group and of many other metals.

**Electrochemical plants are characterized by media of high aggressiveness: acidic and alkali solutions, presence of strong oxidizers etc. Therefore, at the absence of external current most of the metals and alloys which are used in these plants possess high corrosion resistance provided by their stable passive state.**

**The corrosion damage of these metals occurs due to the attack by leakage currents (predominantly – of anodic direction) which are unavoidable in the electrochemical plants. As a result, the metal potential of the attacked structure shifts to the value of its activation that leads to corrosion damage of a local character.**

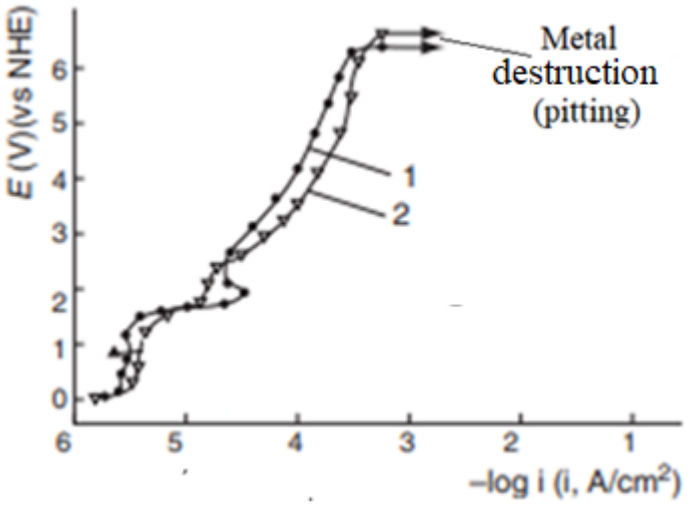
**The basic principle which made possible to protect the structural passive metals under the considered conditions can be formulated as follow: By all means retain the metal potential inside the boundaries of its passive state.**

**This principle can be illustrated by example of titanium piping protection from attack by anodic current in chloride solution of sodium chloride electrolysis.**

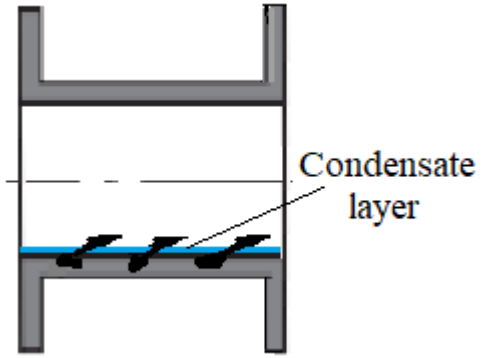
# *A part of chlorine-alkali manufacture*

# *Protection of titanium header from leakage current attack by titanium sacrificial anodes*

**Potentiodynamic anodic polarization plots on titanium (1, 2) and on titanium with ruthenium dioxide coating in NaCl solutions: 300 g/l (1) and 1 g/l (2) at 90°C**




**Insert of titanium – sacrificial anode**

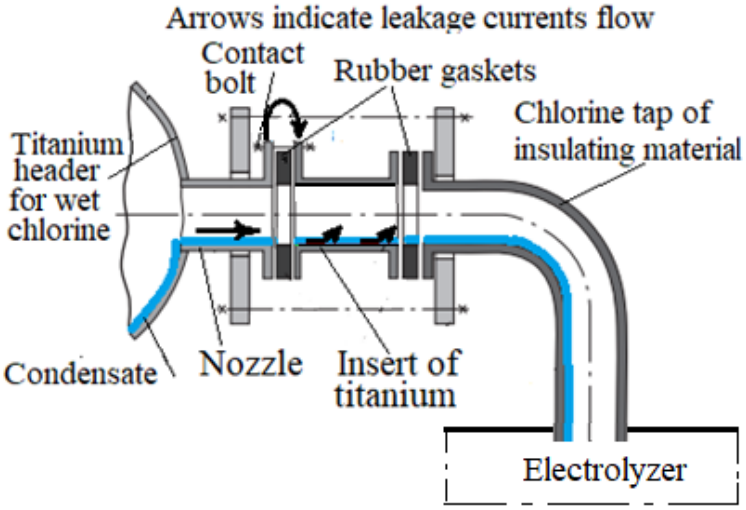



**Corrosion of titanium insert-sacrificial anode after 2 weeks of service**

**Anodic reaction-titanium destruction:**

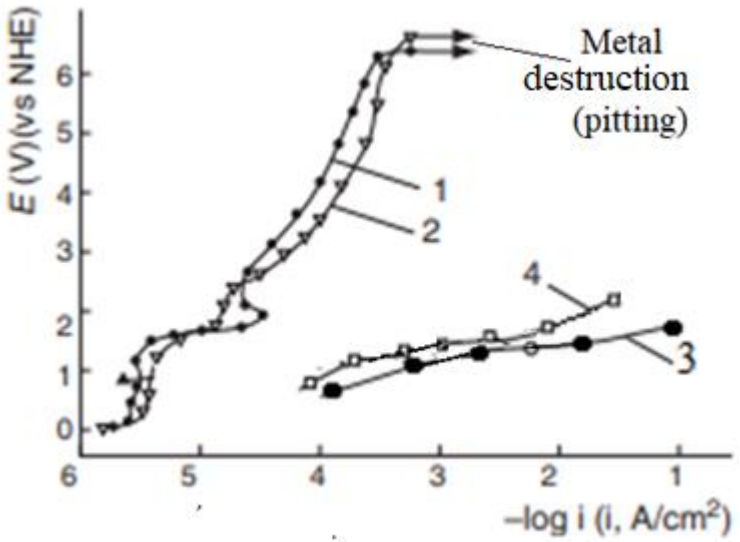
$Ti = Ti^{2+} + 2e^-$

**Protection of titanium header by inserts-sacrificial anodes**

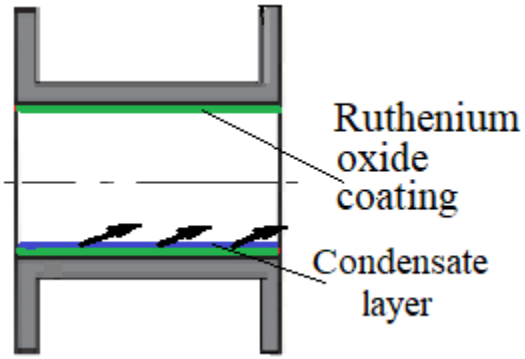


# *Protection of titanium header from leakage current attack by anodes – current leak-offs*

**Potentiodynamic anodic polarization plots on titanium (1, 2) and on titanium with ruthenium dioxide coating in NaCl solutions: 300 g/l (1, 2) and 1 g/l (3,4) at 90°C**




**Anode-current leak-off of titanium with ruthenium oxide**

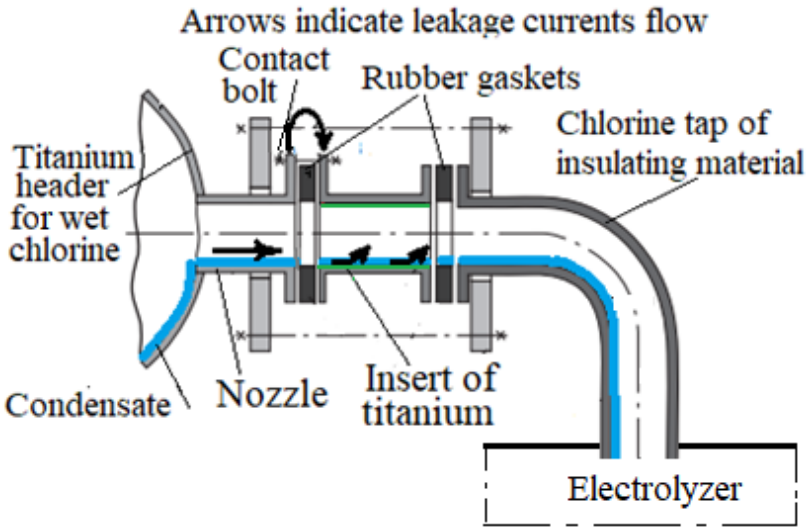



**Anodic reactions:**

$2Cl^- = Cl_2 + 2e^-$

$2H_2O = O_2 + 4H^+ + 4e^-$

**Protection of titanium header by anodes – current leak-offs**



# *Titanium collector protected from corrosion by anodes-current leak-offs*

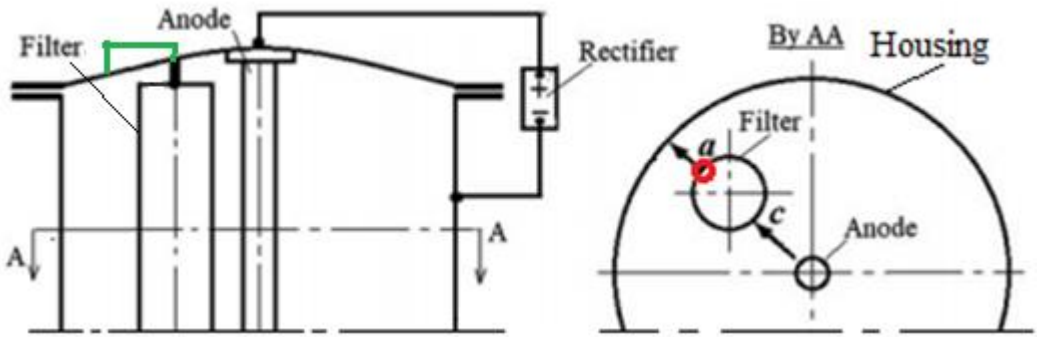
# *Resume*

**Book “Electrocorrosion and Protection of Metals”, second edition, includes extensive information on corrosion and protection of metals under the attack of different kinds of external currents in different brunches of industry.**

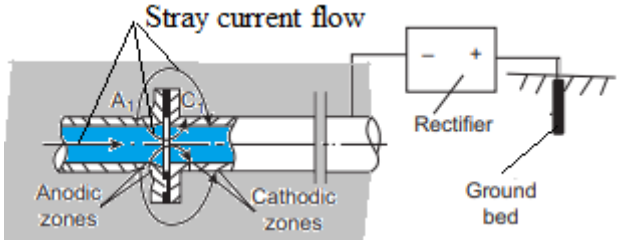
**It is important to note that all this information is concentrated and represented in one book.**

# Corrosion of insulated parts of cathodic protection systems

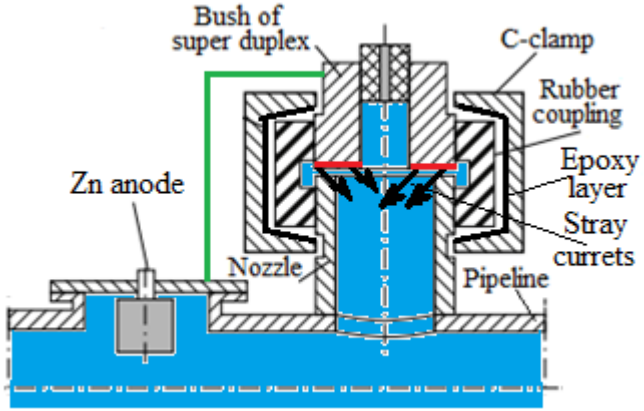
**Schematic of a filter for seawater cleaning with cathodic protection of housing by impressed current or by sacrificial anodes**

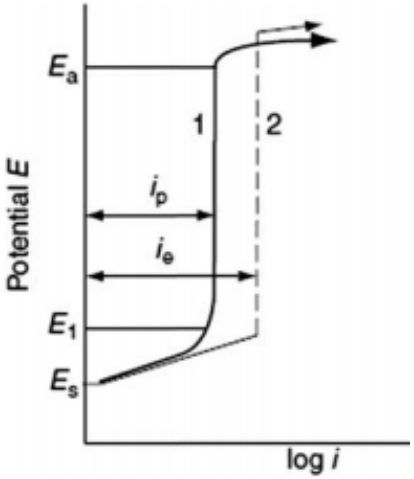



**Stray current flow and consequent corrosion damages at a cathodically protected pipeline.**




**Sampler connection with a cathodically protected pipeline**



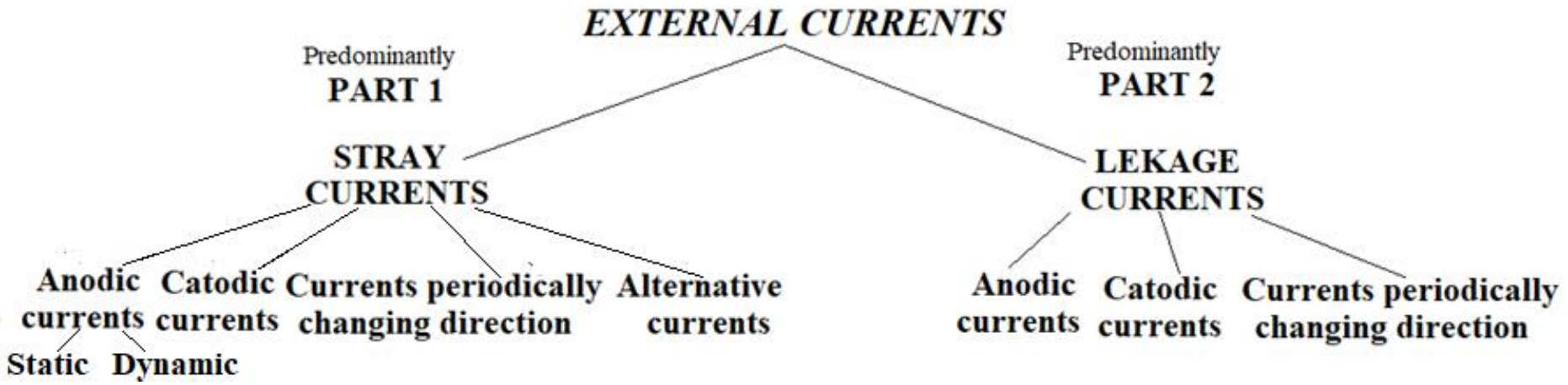



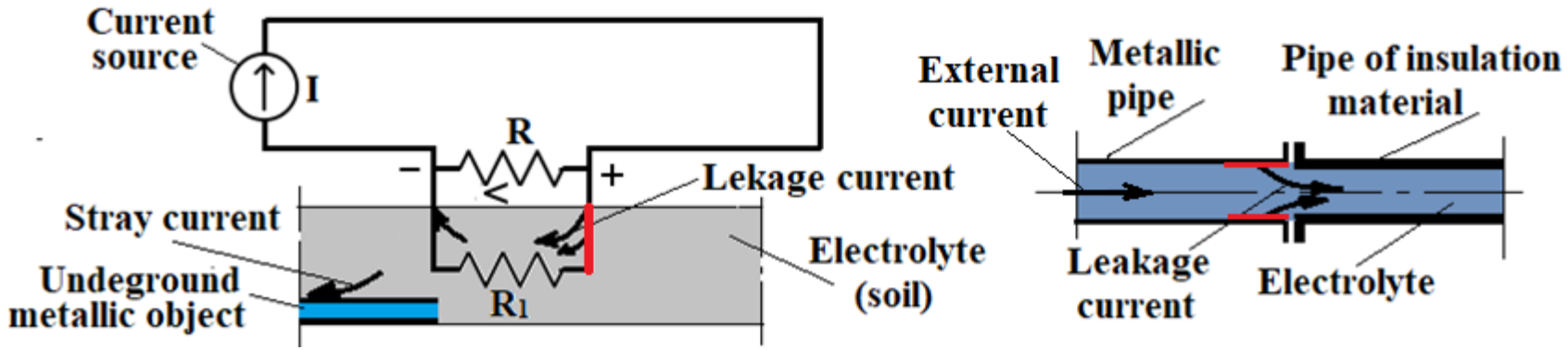

**Anodic polarization plot on a passive metal:**

**1 - potentiostatic;**
**2 – galvanostatic;**
**$E_a$ – activation potential;**
**$i_p$ – current density in a passive state;**
**$i_e$ – external current density**

**Corrosion in seawater of a bush made of super duplex after less than one year of operation**

# *Kinds of external currents attacking metal structures*




In the moment, when the current leaks off from the current source or from some metallic parts connected directly to this source, it is most convenient to designate it as **“leakage current”.** In most cases the areas where the currents flow down from the metal into the electrolyte can be determined from the beginning. The term **“stray current”** is defined as an electrical current flowing through electrical paths other than the intended paths. In most cases, particularly, under the ground, these paths are unknown.

**In both parts of the book the external currents of anodic direction received the primary attention.**

# *Metals considered under the attack of external currents*

**Carbon steel (predominantly in Part 1)**

**Stainless steels (Parts 1 and 2);**

**Aluminum (Part 1);**

**Copper and copper alloys (Part 1);**

**Lead (Part 1);**

**Nickel (Part 2);**

**Titanium and titanium alloys (Part 2);**

**Tantalum (Parts 1 and 2).**

# PART 1 Corrosion and Electrocorrosion of Metals. Corrosion by Stray Currents and Protection Methods