Cathodic Protection Technologist Level 3

Theory and Case-Based Exams

Exam Preparation Guide

Table of Contents

Appendices:

Target Audience

AMPP Cathodic Protection Technologist certification is targeted towards Candidates who have extensive field experience. Candidates for this exam should have a strong knowledge and understanding of both the theoretical concepts and the practical application of cathodic protection. Candidates should have a good understanding of mathematical procedures and a working knowledge of corrosion processes.

How do I know that I have the knowledge and skills needed for this level of Certification?

Introduction

The Cathodic Protection Technologist Exam (CP 3) is designed to assess the necessary knowledge and skills of candidates who desire to be granted industry recognition as an AMPP certified - Cathodic Protection Technologist.

1. Candidates for this exam should have a thorough understanding of the theoretical concepts and the practical application of cathodic protection, including the:
    a. Knowledge and understanding of theoretical CP concepts,
    b. Knowledge and skills to perform most types of field level measurements and surveys,
    c. Knowledge and skills related to procedures and the performance of how field level data is obtained and accepted,
    d. Knowledge and skills related to the interpretation of cathodic protection data,
    e. Knowledge and skills related to the troubleshooting of all type of cathodic protection systems,
    f. Knowledge and skills related to the mitigation options available for identified problems,
    g. Knowledge and skills related to the basic-to-intermediate design calculations for galvanic and impressed current protection system designs.

To help clarify intended roles and responsibilities, the following table provides guidance of the technical oversight (supervision[1]) for a Cathodic Protection Technologist:

Task	Cathodic Protection Technologist (CP3)
Testing	• Can perform, lead, and document most levels of cathodic protection testing, measurement, survey, and/or inspection services • Is able to recognize and perform additional field testing as required, including troubleshooting. • Is able to recognize where highly complex or unique testing or inspections are encountered that may require direct oversight or support of a Cathodic Protection Specialist (CP4)
Data Analysis	• Is able to understand how the data was obtained (procedures and performance) • Is able to interpret and analyze the data, including an understanding of the underlying electrochemistry of the situation. • Is able to recognize where highly complex or unique situations are encountered that may require direct oversight or support of a Cathodic Protection Specialist (CP4)
Installation Support	• Can provide installation support and recommendation for most situations • Is able to recognize where highly complex or unique situations are encountered that may require direct oversight or support of a Cathodic Protection Specialist (CP4)
Commissioning	• Is able to perform and lead most commission activities • Is able to determine and provide oversight for commissioning that can be performed by a Cathodic Protection Technician (CP2) • Is able to recognize where highly complex or unique situations are encountered that may require direct oversight or support of a Cathodic Protection Specialist (CP4)
Design	• Is able to lead basic-to-intermediate level galvanic current designs on single structure systems. • Is able to recognize when the design for complex, critical, or high-risk structures may require direct oversight of a Cathodic Protection Specialist (CP4)
Supervision Authority	• As required by the owner /agency and or AMPP guidelines for direct / indirect supervision of CP1 and CP2 certified individuals.
This table is for guideline and reference purposes only. See the AMPP website for more information.	

[1] The term “supervision” refers to technical oversight and not general supervision of employment.

A. Knowledge and Skills Assessment Guidance

Candidates can review the information attached to this exam preparation guide (EPG) to perform a self-assessment and / or as a study guide for this level of certification – Cathodic Protection Technologist (CP3).

Because this certification is currently the second highest-level credential for Cathodic Protection, there are knowledge and skills which are unique to this level. A part of this body of knowledge and skill may need to have been obtained at lower CP certification levels.

The following critical areas of this exam preparation guide (EPG) can help you prepare for this certification exam:

See Appendix A of this exam preparation guide (EPG) for exam blueprint information related to knowledge and skills.

See Appendix B of this exam preparation guide (EPG) for preparation training and study materials .

See Appendix C of this exam preparation guide (EPG) for equation preparation and study materials .

See Appendix D of this exam preparation guide (EPG) for table / scale preparation and study materials .

How do I become Certified at this level?

Certification Requirements

There are requirements that a Candidate must meet in order to be granted industry credentialing as an AMPP Cathodic Protection Technologist (CP3). These requirements are:

1. Meet work experience and education requirements
2. Meet prerequisite requirements
3. Take and successfully complete all required exam(s)
4. Complete and apply for certification.
5. Accept terms and conditions
6. Pay application fee where applicable

> **See Appendix E of this exam preparation guide (EPG) for more information on certification requirements.**

A. Certification Progression Note

The Cathodic Protection Technologist (CP 3) <u>is not intended as a direct progression</u> from Cathodic Protection Technician (CP 2). The Candidate needs additional industry experience and knowledge:

- Additional experience beyond that of a CP 2 is critical to a candidate's success on this exam. This experience relates to all aspects of CP including:
  - Practical testing and design experience across the different types of facilities and electrolytes, and
  - Formal or equivalent CP educational experience and knowledge studies related to such areas as : math, geology, chemistry, and / or engineering
- Prior to scheduling the Cathodic Protection Technologist exam (CP 3) it is strongly recommended that candidates successfully complete or have an equivalent level of training to:
  - Cathodic Protection Technician Course (CP 2)

- Prior to scheduling the Cathodic Protection Technologist exam (CP 3) it is strongly recommended that candidates successfully complete or have an equivalent level of training to:
  - Cathodic Protection Technologist Course (CP 3)

What will the Certification Exam be like?

Certification Exam Information

There are certification exam requirements that a Candidate must meet in order to be an AMPP Cathodic Protection Technologist (CP3). The Cathodic Protection Technologist Exam includes exam questions related to Theory and to Case-based or scenario studies. More information is provided below:

A. Exam Elements – Theory and Cased-Based

1. **Theory Exam** - in summary consists of 75 multiple-choice questions that require the candidate to demonstrate their "application of knowledge" based on the entire Cathodic Protection (CP) body of knowledge.

Exam Name	AMPP -Cathodic Protection Technologist Theory Exam
Exam Code	NACE-CP3-001[2]
Time	4 hours[3]
Number of Questions	70 exam questions that are scored 5 exam questions that are unscored[4]
Format	Computer Based Testing- CBT

[2] The Theory and Case-Based exams are administered separately. You will receive a pass/fail grade upon completion of each exam. Candidates must pass both exams.
[3] Exam time includes 4 minutes for the non-disclosure agreement and 6 minutes for the system tutorial.

2. **Case-Based Exam** – in summary consists of 37 multiple-choice questions related to a case study, scenario, or problem that requires the application of candidate knowledge based on the entire Cathodic Protection (CP) body of knowledge.

Exam Name	AMPP -Cathodic Protection Technologist Case-Based Exam
Exam Code	NACE-CP3-Case[2]
Time	4 hours[3]
Number of Questions	32 exam questions that are scored 5 exam questions that are unscored[4]
Format	Computer Based Testing- CBT

B. Exam Elements – Sample Exam Questions

This closed-book exam consists of multiple-choice questions. The questions are based on the exam blueprint which reflects the knowledge and skills needed in the CP industry for a Cathodic Protection Technologist.

IMPORTANT **See Appendix F of this exam preparation guide (EPG) for sample exam questions.**

C. Exam Elements – Use of Calculators

Candidates will have access to either a digital TI-108 Standard and / or TI-30XS Scientific calculator for use during the Certification Exam. During the exam, you may have to switch or select one of these calculators for use. <u>Candidates will not be able to use their own calculator for this exam</u>.

IMPORTANT **See Appendix G of this exam preparation guide (EPG) for information on the exam calculator used.**

[4] Unscored exam questions are being evaluated for future exams.

D. Exam Elements – Provided Exam Resources

Candidates will have access to the reference material needed during the exam. This reference material could include such items as:

- industry standards (where indicated in Appendix B)
- equations (where indicated in Appendix C)
- conversion charts (where indicated in Appendix D)
- other where considered appropriate

Note: AMPP course manuals <u>are not available</u> as part of the resources provided for this exam.

Appendix A
Exam Blueprint Information
related to
Knowledge and Skills

Exam Blueprint (CP3)

1. Instruments (1% - 4% Theory and 6% - 13% Case)[1]

A. Understand the operation of a digital volt-ohm meter (multimeter) and how it is used to measure current, voltage, and resistance.

B. Use a volt-ohm meter (multimeter) to determine the voltage and current output of a rectifier.

C. Understand the operation of a soil resistivity meter.

D. Use a volt-ohm meter to determine the current output of sacrificial anodes installed on your system.

E. Conduct a soil resistivity test with a soil resistivity meter or equivalent instrument.

F. Conduct soil resistivity measurements by using a soil box.

G. Understand and be able to perform layer resistivity calculations.

H. Conduct single-point soil resistivity readings with a “Collins Rod”.

I. Install interrupters in rectifiers or bonds for the purpose of taking “on” and “instant-off structure-to-electrolyte potential readings.

J. Understand the various types of pipe locating instruments and be able to utilize them to locate pipelines or cables in all underground environments.

2. Shunts (1% - 3% Theory and 1% - 6% Case)

A. Understand how to determine the amount of current flowing through various size shunts by reading the milli-Volt (mV) drop across it with a Volt-Ohm meter and applying the correct conversion factor.

B. Understand how to determine the direction of current flow through a shunt by observing the polarity of the mV reading.

C. Read shunts in rectifiers to determine the output current.

D. Read shunts in bonds with foreign structures.

E. Read shunts for individual anodes associated with deep well ground beds.

F. Utilize an external shunt to determine the output current of a rectifier with a broken amp meter.

G. Read shunts that are installed in galvanic anodes to determine output current.

[1] This value reflects the proportion of the exam covered (domain weight) by the section indicated.

3. Field Tests (19% - 21% Theory and 22% to 28% Case)

A. Perform current requirement test.

B. Perform soil pH testing.

C. Perform IR-drop testing.

D. Conduct “shorted casing testing” on casings that are suspected of being shorted and interpret the results of the test.

E. Perform coating examinations on sections of pipeline that have been excavated.

F. Perform soil resistivity test to evaluate the area for a conventional ground bed site.

G. Conduct Person, DC voltage gradient (DCVG) and AC voltage gradient (ACVG) surveys to evaluate the coating condition of a section of pipeline.

H. Conduct computerized close interval surveys where needed and evaluate the graphs produced from the data.

I. Locate breaks in header cables with an “audio type” pipe and cable locator.

J. Investigate shorts on a pipeline or other structure.

K. Verify the results of shorted casing test.

L. Understand the factors that affect cathodic protection system performance at the anode, at the structure performance, in the electrolyte, in the metallic path, at the power supply, because of anode arrangement and interference.

M. Perform advanced cathodic protection testing using correct measurement techniques to monitor CP system performance and accurately interpret the data collected to ensure optimum CP system performance.

N. Based on data collected, determine if correction/modifications to system components are necessary.

O. Identify errors in data collection / CP measurements including contact resistance errors, voltage drop errors, and reference electrode errors.

P. Utilize the instruments required to accomplish advanced cathodic protection testing and collection of cathodic protection systems measurements.

Q. Conduct cathodic protection surveys including close interval surveys and DCVG where needed or required and evaluate the graphs produced from the data collected during the surveys.

R. Troubleshoot rectifiers and make corrections or repair as necessary.

S. Perform efficiency test on rectifiers.

T. Install and commission new rectifier installations.

U. Understand in-line and direct inspection (understand and be able to implement ECDA).

4. DC Stray Current Interference (9% - 11% Theory and 6% - 13% Case)

A. Conduct and document interference tests where stray currents are suspected.

B. Once interference tests have been run, suggest a method of control that will mitigate the effects of the stray current.

C. Understand how IR-drop test stations can be used to evaluate stray current.

D. Understand how coupon test stations can be used to determine the presence of and the mitigation of stray current.

E. Calculate the resistance required to provide the amount of current drain desired at a resistance bond installation.

F. Understand the causes (sources) and the effects of interference.

G. Understand the methods available to mitigate interference.

5. AC Mitigation (6% - 9% Theory and 19% - 25% Case)

A. Understand the safety requirements when installing test stations under high voltage power lines.

B. Take appropriate steps to mitigate the effects of excessive AC voltage induced on underground structures.

6. Corrosion Theory (16% - 19% Theory and 1% - 6% Case)

A. Understand the composition of a basic galvanic cell and the electrochemical reactions that allow corrosion to occur at the anode rather than the cathode.

B. Describe the characteristics of anodic and cathodic reactions.

C. Understand and apply the principles of electricity and electrical circuits (series, parallel, and series-parallel circuits) (including the application of Ohm's and Kirchhoff's Laws to electrical circuits.)

D. Perform calculations using Ohm's Law and calculations related to series and parallel circuits.

E. Understand how corrosion cells are formed on metal objects that are underground or otherwise immersed in an electrolyte.

F. Understand Faraday's Law and perform calculations using Faraday's Law to determine required anode weight for cathodic protection.

7. Polarization (9% - 11% Theory and 1% - 6% Case)

A. Understand the cause and effect of polarization in a galvanic cell.

B. Understand activation, concentration, and resistance polarization and the mathematical expressions of these concepts.

C. Understand the factors that affect polarization (area, temperature, relative movement, ion concentration, oxygen concentration).

8. Cathodic Protection (17% - 20% Theory and 13% - 19% Case)

A. Understand the concept of cathodic protection and be knowledgeable of the components required for both galvanic and impressed current systems.

B. Be able to design and install simplistic forms of galvanic and impressed current cathodic protection facilities.

C. Understand the relationship between cathodic protection and other methods for the mitigation of corrosion.

D. Understand the factors that affect the amount of current required for a cathodic protection system.

E. Understand the NACE criteria for cathodic protection and be able to apply the criteria and adjust CP systems as necessary in order to comply with the criteria defined by the company where the technologist is employed.

F. Understand IR drop and be able to determine the IR drop and apply correction techniques as needed.

G. Understand and apply E-Log-I criteria and construct polarization curves.

H. Understand the concept of current distribution and be able to determine ideal current distribution for CP system considering the factors affecting current distribution (anode-to-cathode separation distance, electrolyte and structure resistivity variation, and current attenuation).

I. Understand the effects of current path geometry, protective coatings, and polarization on current distribution.

9. Design (11% - 14% Theory and 6% - 13% Case)

A. Utilize field data to accomplish the calculations required to design cathodic protection current sources.

B. Select site locations and implement the design of cathodic protection current sources for distribution or transmission pipeline systems.

C. Design cathodic protection systems for the inside of water tanks.

D. Design cathodic protection systems for tank bottoms of above-grade storage tanks (AST).

E. Design cathodic protection systems for underground storage tanks (UST).

F. Work with engineering in the proper use of electrical isolation for newly designed facilities.

G. Provide information on underground coating performance for those selecting coatings for new facilities.

Appendix B

Exam Preparation Training and Study Materials

Suggested Preparation Training (CP3)

1. AMPP Cathodic Protection Technologist - Course CP 3

2. AMPP Cathodic Protection Technician - Course CP 2

3. AMPP Cathodic Protection Tester - Course CP 1

Suggested Preparation Training (CP3)

1. AMPP Cathodic Protection Technologist Exam Preparation Guide (EPG)

2. AMPP Cathodic Protection Technician Exam Preparation Guide (EPG)

3. AMPP Cathodic Protection Tester Exam Preparation Guide (EPG)

Suggested Cathodic Protection Specialist Study Material (CP3)

Books

1. Peabody, A. W. (2001). *Peabody's control of pipeline corrosion* (No. Ed. 2). Including:
   - Derived from equations in “Calculation of Resistance to Ground,” by H.B. Dwight. Electrical Engineering, (1936).
   - Derived from equations in “Earth Conduction Effects in Transmission Systems,” by Erling D., Sunde. D. Van Nostrand Co., Inc. (1949).
2. *Corrosion Tests and Standards: Application and Interpretation–Second Edition*. (2005). Baboian, R. ASTM
3. *Handbook of Cathodic Corrosion Protection–Third Edition.* Von Baeckmann, W., Schwenk, W., Prinz, W. (1997) Gulf Professional Publishing.
4. *Atlas of Electrochemical Equilibria in Aqueous Solutions*. Pourbaix, M. (1974). NACE.
5. *NACE Corrosion Engineers Reference Handbook*, Baboian, 3rd Edition (2002)
6. *Pipeline Corrosion and Cathodic Protection*, Parker, M.E. 3rd Edition (1999)
7. *Deep Anode Systems: Design, Installation, and Operation, Lewis, T.H.* (2000). NACE.

Standards[1]

1. NACE SP 0169 (2013), "Control of External Corrosion on Underground of Submerged Metallic Piping Systems." NACE International.

2. NACE SP 0177 (2014), "Mitigation of Alternating Current and Lightning Effects on Metallic Structures and Corrosion Control Systems."

3. NACE SP 0285 (2011), "Corrosion Control of Underground Storage Tank Systems by Cathodic Protection"

4. NACE SP 0193 (2016), "External Cathodic Protection of On-Grade Carbon Steel Storage Tank Bottoms"

5. NACE SP 0176 (2022), "Corrosion Control of Submerged Areas of Permanently Installed Steel Offshore Structures Associated with Petroleum Production"

6. NACE SP 0204 (2015), "Stress Corrosion Cracking (SCC) Direct Assessment Methodology"

7. NACE SP 21424 (2018), "Alternating Current Corrosion on Cathodically Protected Pipelines: Risk Assessment, Mitigation, and Monitoring."

8. NACE SP 0200 (2014), "Steel-Cased Pipeline Practices."

9. NACE SP 0575 (2007), "Internal Cathodic Protection (CP) Systems in Oil-Treating Vessels."

10. NACE TM 0102 (2002). "Measurement of Protective Coating Conductance on Underground Pipelines."

Other Resources

1. NACE SP 0207 (2007), "Performing Close Interval Potential Surveys and DC Surface Potential Gradient Surveys on Buried or Submerged Metallic Pipelines."
2. NACE SP 0497 (2012), "Measurement Techniques related to Criteria for Cathodic Protection on Underground or Submerged Metallic Piping Systems"
3. NACE SP 0102 (2002), "Measurement of Protective Coating Electrical Conductance on Underground Pipelines."
4. NACE SP 0290 (2007), "Impressed Current Cathodic Protection of Reinforcing Steel in Atmospherically Exposed Concrete Structures."
5. NACE SP 0196 (2015), "Galvanic Anode Cathodic Protection of Internal Submerged Surfaces of Steel Water Storage Tanks."

[1] Where appropriate, candidates may have access to all or part of this reference material as part of the exam.

6. NACE SP 0575 (2007), “Internal Cathodic Protection (CP) Systems in Oil-treating Vessels.”
7. NACE SP 0286 (2007), “Electrical Isolation of Cathodically Protected Pipelines.”
8. NACE TM 0115 (2015), “Cathodic Disbondment Test for Coated Steel Structures Under Cathodic Protection.”
9. NACE SP 0104 (2014), “The Use of Coupons for Cathodic Protection Monitoring Applications.”
10. NACE SP 0408 (2014), “Cathodic Protection of Reinforcing Steel in Buried or Submerged Concrete Structures.”
11. NACE SP 0100 (2014), “Cathodic Protection to Control External Corrosion of Concrete Pressure Pipelines and Mortar-coated Steel Pipelines for Water or Wastewater Service.”
12. NACE SP 0294 (2016), “Testing of Embeddable Impressed Current Anodes for Use in Cathodic Protection of Atmospherically Exposed Steel-reinforced Concrete.”
13. NACE SP 0572 (2007), “Design, Installation, Operation, and Maintenance of Impressed Current Deep Anode Beds.”
14. NACE TM 0105 (2016), “Evaluation of Coatings Containing Conductive Carbon Pigmentation for use as an Anode on Atmospherically Exposed Reinforced Concrete.”
15. NACE RP 0375 (2006), “Field-Applied Underground Wax Coating Systems for Underground Pipelines, Application, Performance, and Quality Control.”
16. NACE TM 21423 (2017), “Test Method for Determination of Substrate and Surface Temperature Limits for Insulative Coatings used for Personnel Protection.”
17. NACE MR 0174 (2007), “Selecting Inhibitors for Use as Sucker-rod Thread Lubricants.”
18. NACE TM 0404 (2004), “Offshore Platform Atmospheric and Splash Zone New Construction Coating System Evaluation.”
19. NACE TM 0304 (2004), “Offshore Platform Atmospheric and Splash Zone Maintenance Coating System Evaluation.”
20. NACE SP 0107 (2017), “Electrochemical Realkalization and Chloride Extraction for Reinforced Concrete.”
21. NACE SP 0187 (2017), “Design Considerations for Corrosion Control of Reinforcing Steel in Concrete.”
22. NACE SP 0487 (2007), “Consideration in the Selection and Evaluation of Rust Preventives and Vapor Corrosion Inhibitors for Interim (temporary) Corrosion Protection.“
23. NACE No. 12/AWS C2.23M/SSPC CS 23, “Specification for the Application of Thermal Spray Coatings (Metallizing) of Aluminum, Zinc, and their Allows and Composites for the Corrosion Protection of Steel.”
24. NACE TM 0183 (2018), “Evaluation of Internal Plastic Coatings for Corrosion Control of Tubular Goods in an Aqueous Flowing Environment.”
25. NACE TM 0113 (2013), “Evaluating the accuracy of Field-grade Reference Electrodes.”

26. American National Standard for Use of the International System of Units (SI): The Modern Metric System ASTM SI 10. (2002). ASTM

27. ASTM G97-97 (2013), “Standard Test Method for Laboratory Evaluation of Magnesium Sacrificial Anode Test Specimens for Underground Applications.”

28. ASTM B418 16-a, “Standard Specification for Cast and Wrought Galvanic Zinc Anodes.”

29. DIN 30676 (1985-10), “Design and Application of Cathodic Protection of External Surfaces.”

30. CSN EN 12954, “Cathodic Protection of Buried or Immersed Metallic Structures – General Principles and Application for Pipelines.”

31. ISO 15589-1 (2015), “Petroleum, Petrochemical and Natural Gas Industries – Cathodic Protection of Pipeline Systems – Part 1: On-land Pipelines.”

32. ISO 18086 (2015), “Corrosion of Metals and Alloys – Determination of AC Corrosion-Protection Criteria.”

33. “A Comparison of Anodes for Impressed Current Systems,” Jakobs, J.A., NACE Canadian Region, Western Conference.(1980)

34. “Soil Investigation Employing a New Method of Layer-Value Determination for Earth Resistivity Interpretation,” Barnes, H.E. (1952). Michigan State Highway Department.

35. “Improved Pipe-to-Soil Potential Survey Methods, PRCI Final Report,” PR-186-807. Thompson, N.G., Lawson, K.M. (1991)

Appendix C

Equation Preparation and Study Materials

Calculation Resource

NOTE: All CP3 references, including equations, were taken from original sources and may differ from those used in course manuals and presentations

RESISTANCE TO EARTH OF SINGLE VERTICAL ANODE

$$R_v = \left[\frac{0.00521\rho}{L}\right]\left[\ln\left[\frac{8L}{d}\right] - 1\right]$$

Where:

R_v = resistance (Ω)
ρ = resistivity (Ω-cm)
L = anode length (ft)
d = anode diameter (ft)

OR

$$R_v = \left[\frac{\rho}{2\pi L}\right]\left[\ln\left[\frac{8L}{d}\right] - 1\right]$$

Where:

R_v = resistance (Ω)
ρ = resistivity (Ω-m)
L = anode length (m)
d = anode diameter (m)

RESISTANCE TO EARTH OF MULTIPLE VERTICAL ANODES

$$R_v = \left[\frac{0.00521\rho}{NL}\right]\left[\ln\left[\frac{8L}{d}\right] - 1 + \left[\frac{2L}{S}\right]\ln(0.66N)\right]$$

Where:

R_v = resistance (Ω)
ρ = resistivity (Ω-cm)
L = anode length (ft)
N = number of anodes
S = anode spacing center-to-center (ft)
d = anode diameter (ft)

OR

$$R_v = \left[\frac{\rho}{2\pi NL}\right]\left[\ln\left[\frac{8L}{d}\right] - 1 + \left[\frac{2L}{S}\right]\ln(0.66N)\right]$$

Where:

R_v = resistance (Ω)
ρ = resistivity (Ω-m)
L = anode length (m)
N = number of anodes
S = anode spacing center-to-center (m)
d = anode diameter (m)

NOTE: Use the units specified.

RESISTANCE TO EARTH OF SINGLE HORIZONTAL ANODE

$$R_H = \left[\frac{0.00521\rho}{L}\right]\left[\ln\left[\frac{4L^2+4L\sqrt{S^2+L^2}}{dS}\right]+\frac{S}{L}-\frac{\sqrt{S^2+L^2}}{L}-1\right]$$

Where:

- R_H = resistance (Ω)
- ρ = resistivity (Ω-cm)
- L = anode length (ft)
- S = twice the anode depth (ft)
- d = anode diameter (ft)

OR

$$R_H = \left[\frac{\rho}{2\pi L}\right]\left[\ln\left[\frac{4L^2+4L\sqrt{S^2+L^2}}{dS}\right]+\frac{S}{L}-\frac{\sqrt{S^2+L^2}}{L}-1\right]$$

Where:

- R_H = resistance (Ω)
- ρ = resistivity (Ω-m)
- L = anode length (m)
- S = twice the anode depth (m)
- d = anode diameter (m)

RESISTANCE TO EARTH OF MULTIPLE HORIZONTAL ANODES

$$R_T = \frac{R_H}{N}F$$

Where:

- R_T = resistance of multiple horizontal anodes (Ω)
- F = Anode Interference or Crowding Factor
- R_H = resistance of single horizontal anode (Ω)
- N = number of anodes

ANODE INTERFERENCE BETWEEN ANODES (Crowding Factor)

$$F = 1 + \frac{\rho}{\pi S R_H}\ln[0.66N]$$

Where:

- F = Anode Interference or Crowding Factor
- ρ = resistivity in (Ω-m)
- R_H = resistance of single horizontal anode (Ω)
- N = number of anodes
- S = distance between anodes (m)

KIRCHHOFF'S LAW

$$\mathrm{V_m} = \frac{\mathrm{R_m}}{\mathrm{R}_t}\ \mathrm{E}_t$$

Where:

- V_m = voltage drop across the voltmeter
- R_m = voltmeter input resistance
- R_t = total resistance
- E_t = true potential

PIPE OR CABLE RESISTANCE FROM RESISTIVITY (Pouillet's Law)

$$R = \frac{\rho L}{A}$$

Where:

R = resistance (Ω)
ρ = resistivity in ohm-cm
A = cross-sectional area in cm^2
L = length in cm

LENGTH OF BARE STRUCTURE RECEIVING PROTECTION

$$L = 2d \tan 60°$$

Where:

d = perpendicular distance between anode and structure
L = length of structure receiving protection

TEMPERATURE CONVERSION

$$°\mathrm{C} = \frac{5}{9}(°\mathrm{F} - 32°)$$

$$°\mathrm{F} = \frac{9}{5}(°\mathrm{C} + 32°)$$

WENNER SOIL RESISTIVITY

$$\rho = 2\pi AR$$

Where:

ρ = soil resistivity in (Ω)
A = distance between probes in cm
R = soil resistance (Ω) {instrument reading}

OR

$$\rho = 191.5\,AR$$

Where:

ρ = soil resistivity in ohm-cm
A = distance between probes in feet
R = soil resistance (Ω) {instrument reading}

COATING CONDUCTANCE TESTING

Applicable Formulas:

- Applied Test Current $= \mathrm{I_T}$
- Voltage Shift resulting from Applied Test Current ΔV_1 and ΔV_2
- Resistance-to-earth of Pipe, $R_p = \frac{\Delta V_{AVG}}{\Delta I_T}$
- Pipe Coating Resistance, $\mathrm{R_C} = \mathrm{R_p} * \mathrm{A}$, where $\mathrm{A} = \pi \mathrm{dl}$
- Pipe Coating Conductance, $S = \frac{1}{R_c}$

TRUE POTENTIAL- Input Impedance Measurement Correction

$$E_{true} = \frac{V_h(1-K)}{1 - \left| K\left(\frac{V_h}{V_l}\right) \right|}$$

Where:

E_{true} = true potential (V)
K = input resistance ratio R_l/R_h
R_l = lowest input resistance (Ω)
R_h = highest input resistance (Ω)
V_l = voltage measured with lowest input resistance (V)
V_h = voltage measured with highest input resistance (V)

$$\frac{V_m}{E_{true}} = \frac{R_m}{R_t}$$

Where:
V_m = Voltage of the meter
E_{true} = True potential difference
R_m = Meter resistance
R_t = Reference electrode resistance to earth

CALCULATING RESISTANCE OF THE CIRCUIT

$$R_{circ} = R_t - R_m$$

Where:
R_{circ} = Resistance in the measuring circuit, excluding the meter resistance

CALCULATING PIPE RESISTANCE TO REMOTE EARTH

$$R_{p,re} = \frac{(V_{on} - V_{off})}{I_t}$$

Where:

- $R_{p,re}$ = resistance at remote earth in ohms
- V_{on} = V_{DC} with test current "on"
- V_{off} = V_{DC} with test current "off"
- I_t = test current

$$R_{p,re} = \frac{r_c'}{I_t}$$

Where:

- $R_{p,re}$ = resistance at remote earth in ohms
- r_c' = specific coating resistance
- I_t = test current

REFERENCE ELECTRODE TEMPERATURE CONVERSION

$$E = E°_{25°C_{SHE}} + k_t(T - 25°C)$$

Where:

K_t = temperature coefficient in $\frac{mV}{°C}$
E_t = reference potential at temperature T in $°C_{SHE}$
$E°_{25°C_{SHE}}$ = reference potential at 25°C

ATTENUATION

$$\alpha = \sqrt{rg}$$

Where:

α = attenuation constant
r = longitudinal resistance of structure (Ω)
g = conductance to earth in S

$$r' = R_L A_S$$

Where:

r' = specific leakage resistance (Ω-m^2 (Ω-ft^2))
R_L = average total leakage resistance (Ω)
A_S = total surface area (m^2 (ft^2))

$$R_G = \sqrt{\frac{r}{g}}$$

Where:

R_G = characteristic resistance
r = longitudinal resistance (Ω) of structure
g = conductance to earth in S
R_{SS} = resistance (Ω) looking into open line

CALCULATION OF TOTAL CIRCUIT RESISTANCE

$$R_t = \frac{R_m * E_{true}}{V_m}$$

Where:

R_t = Total Circuit resistance
R_m = Input resistance of meter
E_{true} = True Potential (V)
V_m = Potential Measured (V_h)

DETERMINE SPECIFIC COATING RESISTANCE

$$R_{sect@1000\Omega-\mathrm{cm}} = R_{sect} * \frac{1000}{\rho test}$$

Where:

$R_{sect@1000\Omega-\mathrm{cm}}$ = specific coating resistance
R_{sect} = measured resistance
$\rho test$ = soil resistivity

$$g'_c = \frac{1}{r'_c}$$

g'_c = Specific coating conductance
r'_c = Specific coating resistance

AC CURRENT DENSITY

$$i_{AC} = \frac{8V_{AC}}{\rho\pi d}$$

Where:

I_{AC} = AC current density (A / m²)
V_{AC} = AC volts (V)
ρ = soil resistivity (Ω-m)
d = holiday diameter (m)

POWER ARC DISTANCE

When:
p ≤ 1000 Ω-m

$$r = \left(0.08 * \sqrt{If * p}\ \right)$$

OR

When:
p > 1000 Ω-m

$$r = \left(0.047 * \sqrt{If * p}\ \right)$$

Where:
r = power arc distance (m)
If = fault magnitude (kA)
p = soil resistivity (Ω-m)

NERNST EQUATIONS

$$E_M = E_M{}^o + \frac{RT}{nF}\ln\frac{\alpha^{M^{n+}}}{\alpha^{M^o}}$$

Where:

E_M = metal potential
$E_M{}^o$ = metal potential at standard conditions
R = universal gas constant (8.31J * mol^{-1} *°K^{-1})
T = absolute temperature (°K)
n = number of electrons transferred
F = Faraday's Constant (96,500 coulombs)
$\alpha^{M^{n+}}$ = metal ion activity (α=ɏm, where ɏ is the activity coefficient (always <1) and m is the molar concentration of the metal ion)
α^{M^o} = metal activity (assumed to be 1)

BARNES LAYER

$p_{L1=2*\pi*L_1*\,R_{l_1}}$ (Resistivity of Layer 1)

$R_{L2=\frac{R_1 R_2}{(R_1-\,R_2)}}$ (Resistance of Layer 2)

$p_{L2=2*\pi*L_2*\,R_{L2}}$ (Resistivity of Layer 2)

$R_{L3=\frac{R_2 R_3}{(R_2-\,R_3)}}$ (Resistance of Layer 3)

$p_{L3=2*\pi*L_3*\,R_{L3}}$ (Resistivity of Layer 3)

R_{L4}…………, etc.
p_{L4}…………, etc.

Where:
p_{L1} = Resistivity of layer 1 (Ω-m)

R_{L2} = Resistance of layer 2 (Ω)
R_1 = Resistance measured to depth L_1 (Ω)
R_2 = Resistance measured to depth L_2 (Ω)
p_{L2} = Resistivity of the layer 2 (Ω-m)

R_{L3} = Resistance of layer 3 (Ω)
R_2 = Resistance measured to depth L_1 (Ω)
R_3 = Resistance measured to depth L_2 (Ω)
p_{L3} = resistivity of layer 3 (Ω)

Appendix D

Table / Scale Preparation and Study Materials

Table / Scale References[1]

NOTE: All references, including equations, were taken from original sources and may differ from those used in course manuals and presentations

METRIC PREFIXES

Prefix	Symbol	Factor	Power
tera	T	1 000 000 000 000	10^{12}
giga	G	1 000 000 000	10^{9}
mega	M	1 000 000	10^{6}
kilo	k	1 000	10^{3}
hecto	h	100	10^{2}
deca	da	10	10^{1}
(none)	(none)	1	10^{0}
deci	d	0.1	10^{-1}
centi	c	0.01	10^{-2}
milli	m	0.001	10^{-3}
micro	µ	0.000 001	10^{-6}
nano	n	0.000 000 001	10^{-9}
pico	p	0.000 000 000 001	10^{-12}

CONVERSIONS

EMF	electromotive force – any voltage unit
E or e	any voltage unit
V	volts
mV	millivolts
µV	microvolts
I	any amperage unit
mA	milliamperes or milliamps
µA	microampere or microamps
R or Ω	Resistance

1,000,000 volts	= 1 megavolt
1,000 volts	= 1 kilovolt
1.0 volt	= 1000 millivolts
0.100 volt	= 100 millivolts
0.010 volt	= 10 millivolts
0.001 volt	= 1 millivolt
0.000001 volt	= 1 microvolt

1,000,000 amperes	= 1 mega-ampere
1,000 amperes	= 1 kiloampere0 ampere
	= 1000 milliamperes
0.100 ampere	= 100 milliamperes
0.010 ampere	= 10 milliamperes
0.001 ampere	= 1 milliampere
0.000001 ampere	= 1 microampere

1,000,000 ohms	= 1 mega-ohm
1,000 ohms	= 1 kilo-ohm
1.0 ohms	= 1000 milliohms
0.100 ohm	= 100 milliohms
0.010 ohm	= 10 milliohms
0.001 ohm	= 1 milliohm
0.000001 ohm	= 1 micro-ohm

1 meter	= 100 cm
1 meter	= 1000 mm
1 inch	= 2.54 cm
1 foot	= 30.48 c

[1] Candidate will have access to this necessary reference material as part of the exam.

U.S. Customary/Metric Conversion for Units of Measure Commonly Used in Corrosion-Related Publications

1 A/ft^2	= 10.76 A/m^2
1 acre	= 4,047 m^2 = 0.4047 ha
1 A·h/lb	= 2.205 A·h/kg
1 bbl (oil, U.S.)	= 159 L = 0.159 m^3
1 bpd (oil)	= 159 L/d = 0.159 m^3/d
1 Btu	= 1,055 J
1 Btu/ft^2	= 11,360 J/m^2
1 Btu/h	= 0.2931 W
1 Btu/h·ft^2	= 3.155 W/m^2 (K-factor)
1 Btu/h·ft^2·°F	= 5.678 W/m^2·K
1 Btu·in/h·ft^2·°F	= 0.1442 W/m·K
1 cfm	= 28.32 L/min = 0.02832 m^3/min = 40.78 m^3/d
1 cup	= 236.6 mL = 0.2366 L
1 cycle/s	= 1 Hz
1 ft	= 0.3048 m
1 ft^2	= 0.0929 m^2 = 929 cm^2
1 ft^3	= 0.02832 m^3 = 28.32 L
1 ft·lbf (energy)	= 1.356 J
1 ft·lbf (torque)	= 1.356 N·m
1 ft/s	= 0.3048 m/s
1 gal (Imp.)	= 4.546 L = 0.004546 m^3
1 gal (U.S.)	= 3.785 L = 0.003785 m^3
1 gal (U.S.)/min (gpm)	= 3.785 L/min = 0.2271 m^3/h
1 gal/bag (U.S.)	= 89 mL/kg (water/cement ratio)
1 grain	= 0.06480 g = 64.80 mg
1 grain/ft^3	= 2.288 g/m^3
1 grain/100 ft^3	= 22.88 mg/m^3
1 hp	= 0.7457 kW
1 microinch (µin)	= 0.0254 µm = 25.4 nm
1 in	= 0.0254 m = 2.54 cm = 25.4 mm
1 in^2	= 6.452 cm^2 = 645.2 mm^2
1 in^3	= 16.387 cm^3 = 0.01639 L
1 in·lbf (torque)	= 0.113 N·m
1 inHg	= 3.386 kPa
1 inH$_2$O	= 249.1 Pa
1 knot	= 0.5144 m/s
1 ksi	= 6.895 MPa
1 lb	= 453.6 g = 0.4536 kg
1 lbf/ft^2	= 47.88 Pa
1 lb/ft^3	= 16.02 kg/m^3
1 lb/100 gal (U.S.)	= 1.198 g/L
1 lb/1,000 bbl	= 2.853 mg/L
1 mA/in^2	= 0.155 mA/cm^2
1 mA/ft^2	= 10.76 mA/m^2
1 Mbpd (oil)	= 159 kL/d = 159 m^3/d
1 mile	= 1.609 km
1 square mile	= 2.590 km^2
1 mile (nautical)	= 1.852 km
1 mil	= 0.0254 mm = 25.4 µm
1 MMcfd	= 2.832 x 10^4 m^3/d
1 mph	= 1.609 km/h
1 mpy	= 0.0254 mm/y = 25.4 µm/y
1 oz	= 28.35 g
1 oz fluid (Imp.)	= 28.41 mL
1 oz fluid (U.S.)	= 29.57 mL
1 oz/ft^2	= 2.993 Pa
1 oz/gal (U.S.)	= 7.49 g/L
1 psi	= 0.006895 MPa = 6.895 kPa
1 qt (Imp.)	= 1.1365 L
1 qt (U.S.)	= 0.9464 L
1 tablespoon (tbs)	= 14.79 mL
1 teaspoon (tsp)	= 4.929 mL
1 ton (short)	= 907.2 kg
1 U.S. bag cement	= 42.63 kg (94 lb)
1 yd	= 0.9144 m
1 yd^2	= 0.8361 m^2
1 yd^3	= 0.7646 m^3

Common Reference Electrodes and Their Potentials at Temperature Coefficients

Reference Electrode	Electrolyte Solution	Potential @ 25°C ($V/_{SHE}$)	Temperature Co-efficient (mV/°C)
Cu / $CuSO_4$ (CSE)	Sat. $CuSO_4$	+0.316	0.9
Ag / AgCl (SJ) (SSC)	0.6M NaCl (3½%)	+0.256	−0.33
Ag / AgCl (LJ) (SSC)	Sat. KCl	+0.222	−0.70
Ag / AgCl (LJ) (SSC)	0.1N KCl	+0.288	−0.43
Sat. Calomel (SCE)	Sat KCl	+0.244	−0.70
Zn (ZRE)	Saline Solution	−0.79	---
Zn (ZRE)	Soil	−0.80	---

SJ – solid junction LJ – liquid junction

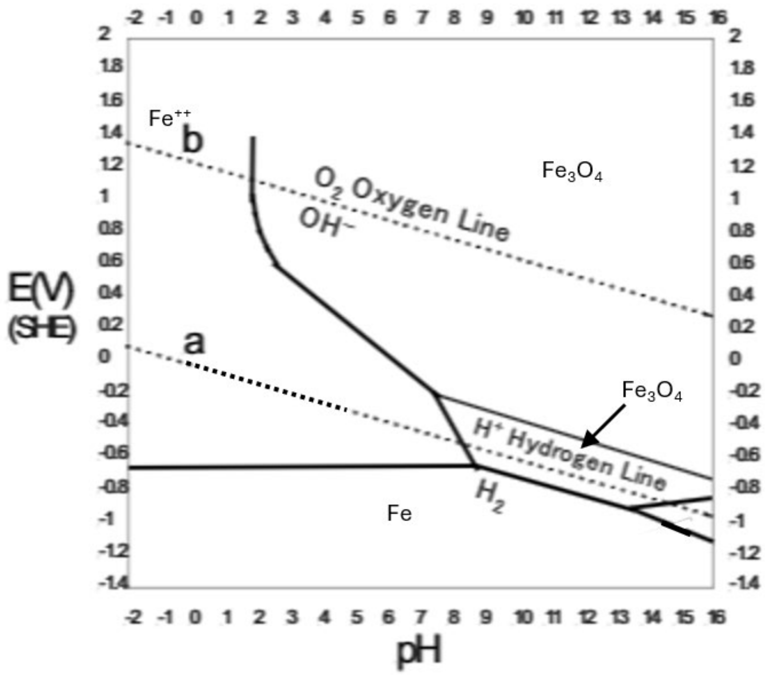
Typical Consumption Rate and Capacities of Different Anode Materials in Soils or Fresh Waters

		Theoretical Consumption Rate		Theoretical Capacity		Typical Efficiency (1)
		kg / A-y	lb. / A-y	A-y / kg	A-y / lb.	%
Galvanic Anode Material	Magnesium	3.98	8.76	0.250	0.114	50
	Zinc	10.76	23.50	0.093	0.042	90
	Aluminum	2.94	6.49	0.340	0.155	85 - 95
Impressed Current Anode	Graphite / Carbon	0.1 to 1.0	0.22 to 2.2	10.1 to 1.0	4.5 to 0.45	
	High Silicon Iron	0.25 to 1.0	0.55 to 2.2	4.0 to 1.0	1.8 to 0.45	
	Steel	9.1	20	0.11	0.05	90

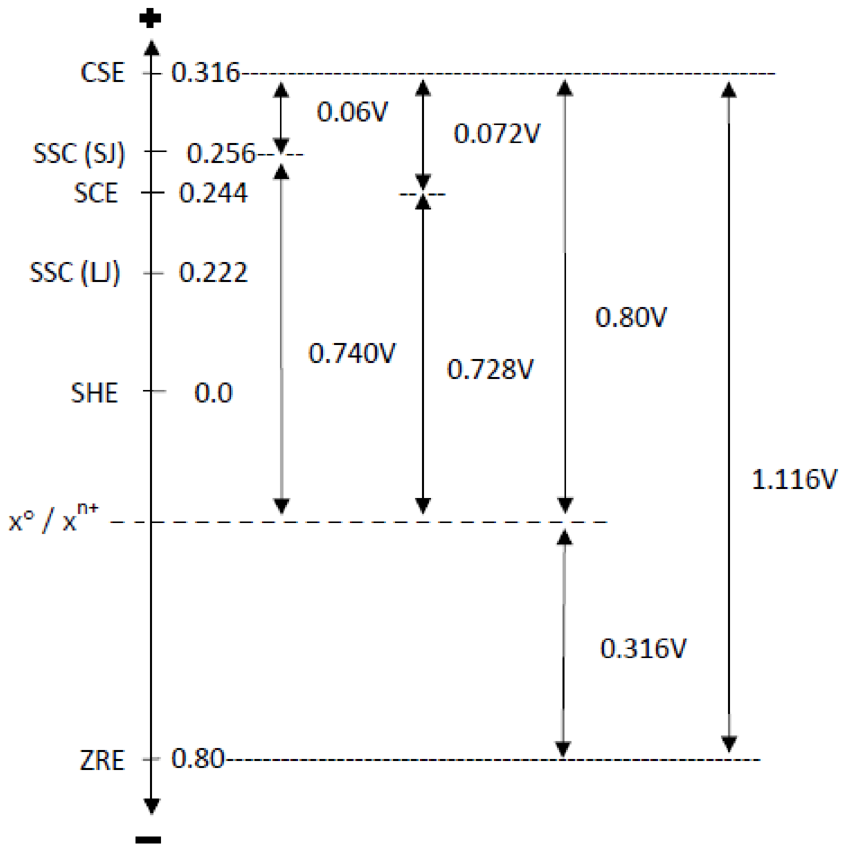
Note: Platinum-clad and mixed metal oxide coated anodes are quantified by thickness of the surface film rather than by weight.

(1)Efficiency of galvanic anodes is dependent on the anode current density.

Typical Potential-pH (Pourbaix) Diagram Iron in Water at 25°C



Reference Electrode Conversion Scale



(SJ) = only solid silver chloride (AgCl) over the silver wire.

(LJ) = a silver wire surrounded by a concentrated solution of KCl.

Appendix E
Certification Requirements

Certification Requirements

Cathodic Protection Technologist (CP3) certification requirements are as follows:

1. **Meet work experience and education requirements:**

Cathodic Protection Technologist (CP3) Certification	
✓	**Option one**
	• Bachelor's degree in either physical science or engineering; and, • 3-years of verifiable work experience in cathodic protection
OR	
✓	**Option two**
	• 2-years post high school training from approved math / science or technical / trade school; and, • 6-years of verifiable work experience in cathodic protection
OR	
✓	**Option three**
	• 8-years of verifiable work experience in cathodic protection

2. **Meet prerequisite requirements:**

✓	**Prerequisite**	Successful completion of the **Ethics for the Corrosion Professional Course** or an accepted training equivalent.
✓	**Prerequisite**	None

3. **Take and successfully complete required exam(s):**

✓	**Certification Exam**	Cathodic Protection Technologist Theory Exam
✓	**Certification Exam**	Cathodic Protection Technologist Case-Based Exam

4. **Complete and Apply for the Certification:**

✓	**Submit an Application**	Candidates must apply for this certification by submitting an on-line application.

- The application is subject to review and approval.
  - Upon successful completion of **all** requirements, AMPP credentialing and certification will grant the candidate industry recognition as an AMPP certified - Cathodic Protection Technologist.
  - Applications to AMPP credentialing and certification must be within 3-years of the successful completion of any certification exam
  - Successful completion of the certification exam(s) by itself <u>does not grant the candidate any use of the certification title.</u>
  - Completion of Cathodic Protection Technologist Course by itself <u>does not grant the candidate any use of the certification title.</u>

5. **Accept Terms and Conditions:**

✓	**Accept Terms and Conditions**	Candidates must agree to the Terms and Conditions

6. **Pay Application Fee where applicable:**

✓	**Pay Application Fee**	Candidates must pay the application fee where applicable

Candidates have a four (4) year certification window in which to complete the certification level[1]

The window starts when any single initial requirement event occurs:

- ✓ Exam completion – any CBT exam completion whether pass or fail.
- ✓ Application – Completion of an application in the Candidate's certification portal
    - Must be submitted and approved with three (3) years of the start of the four (4) year window.
    - Application must be updated and resubmitted after the third year if still in the certification window.

Candidate exam completion restrictions:

Theory and case exam slots are offered on 6-month intervals

- ✓ Candidate's initial attempt to pass
- ✓ A 6-month wait interval per attempt
- ✓ Within the 4-year window
    - Maximum total of eight (8) exam testing attempts for theory
    - Maximum total of eight (8) exam testing attempts for case

[1] If the 4-year window is exceeded, any successfully passed exams must be retaken by the candidate as part of a new 4-year window.

Appendix F

Sample Exam Questions

Practice Exam Questions

Description of Questions

This closed-book exam consists of multiple-choice questions. The questions are based on the exam blueprint knowledge and skills needed in the CP industry for a Cathodic Protection Technologist.

Practice Theory Questions

The following provides sample questions to illustrate the type of content that will be on the exam. You should not consider your performance on the sample questions as a predictor of your performance on the actual exam. The sample questions are for illustrative purposes only.

Theory Type Questions

1. If the potential of -700 $mVDC_{CSE}$ is measured with the reference at 25˚C, what is the measured potential if the reference is at 40˚C?

A. -686 $mVDC_{CSE}$
B. -700 $mVDC_{CSE}$
C. -714 $mVDC_{CSE}$
D. -868 $mVDC_{CSE}$

2. Which of the following conditions will increase galvanic anode polarization?

A. Increased agitation
B. Decreased Mn^{+} ions
C. Decreased temperature
D. Increased surface area

3. How long has this rectifier been OFF during this 30-day period given the following data?

Location	Operating Data
DC Output	15 V_{DC} and 10 A_{DC}
KWH Meter	4 revolutions per minute where K=1
AC Power Consumption	For the 30-day period is 120 KWH

A. 0 days
B. 9 days
C. 12 days
D. 21 days

4. Which of the following discharge current densities would result in the largest corrosion rate according to Faraday's Law?

A. 10 mA/ft^2 from a steel plate
B. 6 μA/cm^2 from a lead plate
C. 100 mA/m^2 from a zinc anode
D. 10 μA/cm^2 from an aluminum anode

Practice Case-Based Questions

The following provides sample questions to illustrate the type of content that will be on the exam. You should not consider your performance on the sample questions as a predictor of your performance on the actual exam. These sample question examples are for illustrative purposes only.

Case-Based Statement

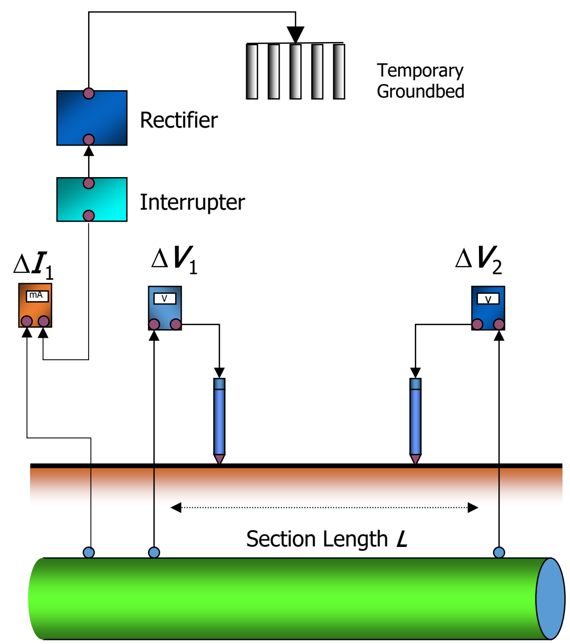
A horizontal directionally drilled (HDD) pipeline is to be installed under a river. The coating quality and cathodic protection (CP) current requirement will need to be assessed prior to the pipeline being welded to (connected to) the upstream and downstream pipeline segments which are already in place. The design information for the HDD pipeline follows:

- 24-inch (609.6-mm) outside diameter
- 4,500 linear feet in length (HDD bore) (0.85-miles or 1.237-km)
- Mill applied - 16-mil of fusion bonded epoxy coating (FBE) with an abrasion resistance overcoat (ARO) of 60-mils
- The girth welds are field coated with a 70-mil thick liquid epoxy coating
- Cathodic protection is to be provided by a local system dedicated to the HDD installed pipeline segment

The design basis for this HDD segment of pipeline includes an accepted Coating Quality Acceptance Table that includes the following information:

Effective Coating Resistance (ohm-ft^2)	Estimate of Coating Quality	Bare Area (%)	Coating Efficiency (%)
Bare	-	100	0
10,000	Poor	3	97
25,000	Fair	1.2	98.8
50,000	Fair	0.6	99.4
100,000	Good	0.3	99.7
500,000	Excellent	0.06	99.94

The approved testing method for this HDD pipeline segment makes use of the following test arrangement:



Applicable field data results can be found in the table below:

Applied test current for this data is: 0.050 A_{DC}		
Pipe-to-Electroyte Potentials	V_1	V_2
Native (static)	-0.700 VDC_{CSE}	-0.630 VDC_{CSE}
Current Applied “ON”	-1.400 VDC_{CSE}	-1.300 VDC_{CSE}
Current Interrupted “Instant-off”	-0.850 VDC_{CSE}	-0.780 VDC_{CSE}

1. What assessment technique is being used to understand the protective coating quality of this HDD pipeline?
   A. Close-interval potential survey
   B. Pipe-to-electrolyte potential measurement
   C. Coating conductance measurement
   D. Coating attenuation survey

2. For the data provided, what is the calculated Pipe-to-earth Resistance R_p?
   A. 3.0 Ω
   B. 10.7 Ω
   C. 13.7 Ω
   D. 16.3 Ω

3. For the data provided, what is the calculated Pipe Coating Resistance R_c?
   A. 52,298 Ω-ft^2 (56,931 Ω-m^2)
   B. 250,364 Ω-ft^2 (1,269,4896 Ω-m^2)
   C. 302,535 Ω-ft^2 (3,257,536 Ω-m^2)
   D. 650,000 Ω-ft^2 (6,996,542 Ω-m^2)

4. For the data provided, what is the calculated Pipe Coating Conductance S?
   A. 1.305 µS
   B. 2.000 µS
   C. 2.300 µS
   D. 3.304 µS

5. Using the data provided, what is the total current required to achieve a minimum polarized pipe potential of -0.900 VDC_{CSE}?
   A. 50.00 mA_{DC}
   B. 90.00 mA_{DC}
   C. 100.00 mA_{DC}
   D. 1500.00 mA_{DC}

6. Using the data provided, rate the quality of the coating found to exist on the HDD after testing?
   A. Poor
   B. Fair
   C. Good
   D. Excellent

Answer Key - Sample Theory Questions

1. C
2. C
3. B
4. B

Answer Key - Sample Case-Based Questions

1. C
2. B
3. C
4. D
5. B
6. C

Appendix G
Exam Calculator

Exam Calculator

Candidates will have access to either a digital TI-108 Standard and / or TI-30XS Scientific calculator for use during the Certification Exam. During the exam, you may have to switch or select one of these calculators for use. Candidates will not be able to use their own calculator for this exam.

Prior to attending your exam session:

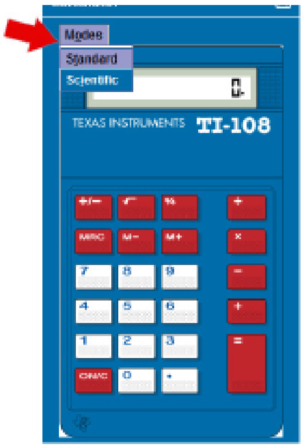
- ✓ It is highly recommended that you review how this calculator operates and how you will use it. Other suggestions:
    - You may be able to find this calculator (TI-30XS) in the Google Store for Android phones to practice on.
        - https://play.google.com/store/apps/details?id=calc991.calculator.scientific.xs30.t34.free&pcampaignid=web_share
        - A similar version may be available for Apple IOS
    - You may wish to purchase a TI-30XS (approximate cost $ 20.00 US dollars)
- ✓ The candidate can use the exam calculator for trigonometric hyperbolic functions like:

- $\sinh x = \frac{e^x - e^{-x}}{2}$

  Key stroke example for sinh x is 2nd, hyperbolic (hyp), sin, enter number,), enter.

- $\cosh x = \frac{e^x + e^{-x}}{2}$
- $\tanh x = \frac{\sinh x}{\cosh x} = \frac{e^x - e^{-x}}{e^x + e^{-x}}$
- $\coth x = \frac{\cosh x}{\sinh x} = \frac{e^x + e^{-x}}{e^x - e^{-x}}$
- $\operatorname{sech} x = \frac{1}{\cosh x} = \frac{2}{e^x + e^{-x}}$
- $\operatorname{csch} x = \frac{1}{\sinh x} = \frac{2}{e^x - e^{-x}}$

Standard Calculator



Standard Mode Functions

Add	[+]	
Subtract	[-]	
Multiply	[X]	
Divide	[÷]	
Negative	[(-)]	
Percentage	[%]	
Square Root	[√]	Example: 4[√]
Reciprocal (Inverse)	x	Example: 1[÷]2[=]
Store value to variable	[M+]	Example: 3[*]5[=][M+]
Access variable	[MRC]	Example: 7[+][MRC][=]
Clear variable	[M-][MRC]	

Scientific Calculator

Scientific Mode Functions

Add	[+]	
Subtract	[-]	
Multiply	[X]	
Divide	[÷]	
Negative	[(-)]	
Percentage	[2nd] [%]	
Square Root	[√]	Example: [2nd][√]4[enter]
Reciprocal (Inverse)	[X^{-1}]	Example: 2[X^{-1}][enter]
Store value to variable	[sto▶] [X^{yzt}]	Example: 3[*]5[enter][sto▶][X^{yzt}][enter]
Access variable	[X^{yzt}] or [2nd] [recall]	Example: 7[+][2nd][recall][enter][enter]

Numeric Notation

Standard (Floating Decimal) Notation (digits to the left and right of decimal	mode menu options **NORM** SCI ENG e.g. 123456.78 FLOAT 0 1 2 3 **4** 5 … e.g. 123456.7800
Scientific Notation (1 digit to the left of decimal and appropriate power of 10)	mode menu options NORM **SCI** ENG e.g. 1.2345678*105
Engineering Notation (numer from 1 to 999 times 10 to an integer power that is a multiple of 3)	mode menu options NORM **SCI** ENG e.g. 123.45678*103

Fractions

Simple fractions	n/d
Mixed numbers	2nd [Un/d]
Conversion b/w simple fraction and mixed number	2nd [n/d ◀ ▶ Un/d]
Conversion b/w fraction and decimal	2nd [f ◀ ▶ d]

Powers, roots, and inverses

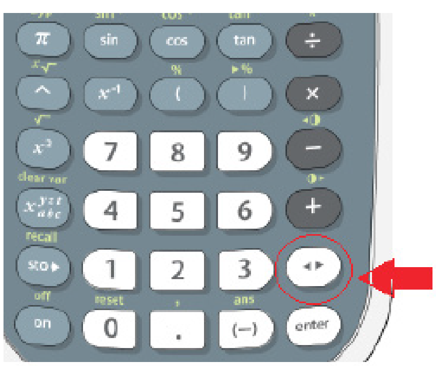
Square a value	x^2	
Cube a value	^	
Raise value to specified power	^	Example (2^4) 2 ^ 4
Square root	2nd [√]	Example (√16): 2nd [√] 16
Reciprocal	x^{-1}	Example (n^{th} root): 5^{th} root of 8: 5 2nd [^{x}√] 8

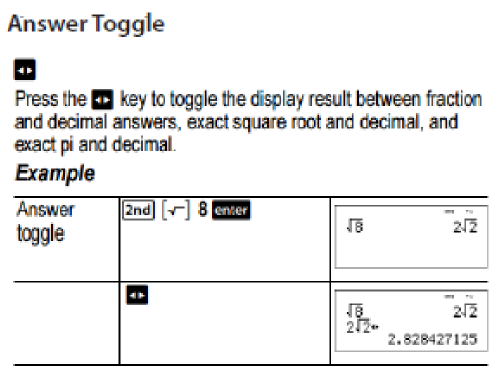
Pi

PI (π)	π

Toggle

The scientific calculator might show the results of certain calculations as a fraction – involving pi or a square root. To convert this kind of result to a single number with a decimal point, you will need to use the "toggle answer" button circled in the picture below. Pressing this button will change the display from a fractional to a decimal format.




Answer Toggle

◀▶

Press the ◀▶ key to toggle the display result between fraction and decimal answers, exact square root and decimal, and exact pi and decimal.

Example

Answer toggle	2nd [√] 8 enter	√8 2√2
	◀▶	√8 2√2 2√2 ▸ 2.828427125

Note: This following option may or may not be available based on testing center.

- If you find this onscreen calculator difficult to use, raise your hand and ask the Test Administrator to provide you with a hand-held calculator. The Test Administrator may be able to provide you with either the scientific or non-scientific calculator model as referenced above.

<u>As a reminder, candidates will not be able to use their own calculator for this exam</u>.