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RECORD OF REVISIONS

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0	06/28/99	Rewritten and reformatted to support LIR 220-03-01. Superseded Facilities Engineering Standards, Volume 6, Electrical, Manual Rev 15, 6/26/98.	David W. Powell, <i>PM-2</i>	Dennis McLain, <i>FWO-FE</i>
1	11/18/02	General revision and addition of endnotes. Replaces Subsections 245.2.1, 245.2.2, 245.2.3, 245.4.1, and 245.8.	David W. Powell, <i>FWO-SEM</i>	Kurt Beckman, <i>FWO-SEM</i>
2	10/27/06	Administrative changes only. Organization and contract reference updates from LANS transition. IMP and ISD number changes based on new Conduct of Engineering IMP 341. Master Spec number/title updates. Other administrative changes.	David W. Powell, <i>FM&E-DES</i>	Kirk Christensen, <i>CENG</i>

G4090 OTHER SITE ELECTRICAL UTILITIES

1.0 CATHODIC PROTECTION

1.1 General

- A. Design, furnish and install cathodic-protection (CP) systems for aboveground and direct-buried or submerged ferrous structures, such as steel tanks and pipelines¹, in accordance with the following codes, standards and this section:²
1. 40 CFR, Part 280, *Technical Standards and Corrective Action Requirements for Owners and Operators of Underground Storage Tanks (UST)*.
 2. 49 CFR, Part 192, *Transportation of Natural Gas and other Gas by Pipeline*.
 3. 49 CFR, Part 195, *Transportation of Hazardous Liquids by Pipeline*.
 4. AWWA D104, *Automatically Controlled, Impressed-Current Cathodic Protection for the Interior of Steel Water Tanks*.
 5. National Association of Corrosion Engineers (NACE) Standard RP0169, *Control of External Corrosion on Underground or Submerged Metallic Piping Systems*.
 6. NACE Standard RP0177, *Mitigation of Alternating Current and Lightning Effects on Metallic Structures and Corrosion Control Systems*.
 7. NACE Standard RP0193, *External Cathodic Protection of On-Grade Carbon Steel Storage Tank Bottoms*.
 8. NACE Standard RP0285, *Corrosion Control of Underground Storage Tank Systems by Cathodic Protection*.
 9. NACE Standard RP0286, *Electrical Isolation of Cathodically Protected Pipelines*.
 10. NACE Standard RP0388, *Impressed Current Cathodic Protection of Internal Submerged Surfaces of Steel Water Storage Tanks*.
- B. Consider CP applicability on all projects; provide a CP system where applicable.³ *CP is a functional requirement for virtually all projects involving new aboveground water tanks, direct buried or submerged metallic structures, or the repair or replacement of similar existing structures.*
- C. *MIL-HDBK-1004/10 is a valuable design guide and reference for cathodic protection principles and practices.*

¹ 49 CFR, Part 192 requires that all metallic natural gas piping be coated and cathodically protected regardless of the soil resistivity. Corrosion control is mandated for all metallic underground storage tanks storing petroleum or hazardous substances by 40 CFR, Part 280 and on Hazardous Liquid Pipelines, (e.g., liquid fuel) by 49 CFR, Part 195.

² Numerous aboveground, direct-buried, and submerged ferrous metallic structures have been installed at LANL without cathodic protection in an effort to reduce first costs or to stay within budget. Leaks due to corrosion can cause environmental damage. Installing a low maintenance cathodic protection system where and when it is required benefits not only LANL but also the public and the environment. Certain types of systems, used for fuels and natural gas, pose safety problems if cathodic protection is not installed and maintained.

³ Refer to 3.1 in NACE RP0169-96

1.2 CP Designer Qualifications and Responsibilities

- A. Use a “corrosion expert” to perform all pre-design surveys, CP designs, and acceptance tests and inspections. The “corrosion expert” must have one or more of the following qualifications:⁴
1. NACE Accredited Corrosion Specialist,
 2. NACE certified CP Specialist, or
 3. Registered professional engineer with documented education and experience in corrosion control of buried or submerged metallic piping and tank systems.
- B. As part of the CP design provide economic justification for selection of the type of CP system (sacrificial or impressed), soil corrosiveness (resistivity, pH, etc.) data, current requirement tests (if applicable), potential survey data (if applicable to existing structures), and all design calculations for CP in the basis of design.⁵
- C. Use a life cycle cost analysis to select pipe material if more than one pipe material (e.g., copper v. steel V. non-metallic) is feasible.⁶ If the ferrous metallic system requires CP, include the cost of that CP design and installation in the life cycle cost analysis comparison.
- D. Identify optimum locations of anodes, rectifiers, test stations, junction boxes, wiring, etc., installation details, insulators, bond connections, and the structure or component connected to the cathodic protection. Coordinate with mechanical, site and other disciplines.⁷
- E. Identify locations where interference testing is warranted (e.g. all pipe that passes within 305 meters of an impressed current anode bed and then crosses the cathodically protected line).⁸
- F. Identify locations where structure-to-soil potential measurements are needed to assure complete protection and/or to ensure that maximum allowed potentials have not been exceeded.⁹
- G. Determine appropriate testing of isolation and bonding of structures and piping systems.¹⁰
- H. Provide recommended tests, formats, required methodology, etc., for the commissioning, final acceptance, and long-term maintenance of the CP System.¹¹

1.3 CP Design

- A. Base CP designs on historical knowledge and specific field tests made at the proposed construction site.¹² *Tests should include, but not be limited to:*

⁴ Refer to 1.3 in NACE RP0169-96, 1.1.5 in NACE RP0285-2002, and 1.8 in NACE RP0388-2001.

⁵ Refer to section 3 in NACE RP0169-96, section 3 in NACE RP0193-2001, section 3 in NACE RP0196-96, and section 3 in NACE RP0388-2001.

⁶ Refer to Appendix B, C, and D in NACE RP0169-96.

⁷ Refer to 7.7 in NACE RP0169-96, 5.8 in NACE RP0193-2001, and 6.6 in NACE RP0285-2002.

⁸ Refer to Section 9 in NACE RP0169-96.

⁹ Refer to 4.5 in NACE RP0169-96.

¹⁰ Refer to Section 8 in NACE RP0286-2002.

¹¹ Refer to sections 10 and 11 in NACE RP0169-96; sections 10 and 11 in NACE RP0193-2001; 7.4, 7.5, and section 8 in NACE RP0285-2002; and section 8 in NACE RP03885-2001.

1. *Soil or water corrosivity (resistivity)*
 2. *Current requirements*
 3. *Potential surveys*
 4. *Stray current interference potential*
 5. *Water chemistry/corrosivity (pH).*
- B. Base CP system designs on providing a protective potential to meet the requirements of NACE Standard RP0169¹³ or RP0285¹⁴, as applicable. *All steel structure-to-earth potentials should be measured in accordance with NACE RP0169 using either minus 850 mv instant off potential and/or 100 mV of cathodic polarization shift.*
- C. Provide both CP and protective coatings for the following buried/submerged ferrous metallic structures, regardless of soil or water resistivity:
1. Natural gas and propane piping¹⁵
 2. Liquid fuel piping¹⁶
 3. Oxygen, hydrogen, nitrogen, argon, and similar gas piping¹⁷
 4. Underground storage tanks¹⁸
 5. Fire protection piping¹⁹
 6. Ductile or cast iron pressurized piping under floor (slab on grade) in soil²⁰
 7. Other structures with hazardous products as identified by the user of the facility.
- D. Provide CP for cast iron pipe as follows:²¹
1. For soil resistivities below 10,000 ohm-cm at pipeline installation depth provide CP, bonded joints, and protective coatings.
 2. When soil resistivity is between 10,000 and 30,000 ohm-cm at pipeline installation depth, provide bonded joints only.

¹² Refer to section 7 in NACE RP0169-96; sections 5, 6, 7, and 8 in NACE RP0193-2001; section 6 in NACE RP0285-2002, section 4 in NACE RP03885-2001.

¹³ Refer to section 6 in NACE RP0169-96.

¹⁴ Refer to section 5 in NACE RP0285-2002.

¹⁵ 49 CFR, Part 192 requires that all metallic natural gas piping be coated and cathodically protected regardless of the soil resistivity.

¹⁶ Corrosion control is mandated for all metallic underground hazardous liquid pipelines, (e.g., liquid fuel) by 49 CFR, Part 195.

¹⁷ Corrosion control requirements mandated in 49 CFR, Part 192 for natural gas piping is extended to other underground gas piping systems.

¹⁸ Corrosion control is mandated for all metallic underground storage tanks storing petroleum or hazardous substances by 40 CFR, Part 280.

¹⁹ Refer to Chapter 7 in NFPA 24, *Standard for the Installation of Private Fire Service Mains and Their Appurtenances*.

²⁰ There is a lack of consensus among corrosion protection experts as to the resistance of unprotected cast-iron and ductile-iron to damage in corrosive conditions. Leakage from pressurized cast-iron or ductile-iron piping under a building slab would cause substantial structural and environmental damage; therefore, CP is required for pressurized cast-iron or ductile-iron piping under a building slab.

²¹ Based on U.S Army Corps of Engineers ETL 1110-3-474 dated 14 July 1995.

- E. Provide CP and/or bonded or unbonded coatings for ductile iron piping systems if indicated by the results of economic analysis and the recommendation by a "corrosion expert."
- F. Dielectrically isolate copper water service lines from ferrous pipe in accordance with NACE RP0286.²²
- G. Provide CP and protective coatings for the following structures if indicated by the results of economic analysis and the recommendation by a "corrosion expert":
 - 1. Gravity sewer lines, regardless of soil resistivity
 - 2. Potable water lines in soil resistivities above 10,000 ohm-cm
 - 3. Other buried/submerged ferrous metallic structures not covered above in soil resistivities above 10,000 ohm-cm.
- H. Provide interior cathodic protection for steel water storage tanks using automatic impressed current systems in accordance with AWWA D104 and NACE RP0388.²³
- I. Design CP for ferrous metallic underground storage tanks as though two and one-half percent (2.5%) of the tank is bare metal.²¹ Use either magnesium or zinc sacrificial anodes. *Composite type underground storage tanks with a 3.2 mm minimum thick layer of fiberglass coating in accordance with UL 1746 and holiday tested at 35,000 volts are exempt from CP requirements.*
- J. Install ferrous metallic pipe passing through concrete so it will not be in contact with the concrete; provide a non-metallic sleeve or a sleeve with waterproof dielectric insulation between the ferrous metal pipe and the sleeve.
- K. Where ferrous metal piping passes through a concrete thrust block or concrete anchor block, either insulate the pipe from the concrete or provide CP.²¹
- L. Using appropriate testing and inspection procedures, verify that CP criteria have been met prior to acceptance of the CP system.
- M. Provide as-built drawings of the CP system showing the location of rectifiers, test stations, anodes, insulated fittings, etc., as applicable. Reference CP component locations to two permanent facilities or marker points.

2.0 SITE GROUNDING

2.1 General

- A. Install site grounding systems in accordance with the NEC, NESC, IEEE Std 142, IEEE Std 80, and this section.

²² Refer to 2.5 in NACE RP0286-2002.

²³ Impressed current systems with automatic controls are preferred so adequate cathodic protection can be maintained and disbonding of tank coatings avoided by proper control of the current output. Refer to Section 7 in NACE RP0388-2001.

- B. Use materials and installation methods described in LANL Master Specifications Section 26 0526, *Grounding and Bonding for Electrical Systems*.

2.2 Grounding Electrode System

- A. Install the grounding electrode systems having calculated ground resistances not exceeding the following values:
1. Aggregate service rated 50 kVA and less: 25 Ohms²⁴
 2. Aggregate service rated more than 50 kVA but less than 2500 kVA: 5 Ohms²⁵
 3. Aggregate service rated 2500 kVA and larger: 1 Ohm²⁶
 4. Manhole grounds: 25 Ohms²⁷
- B. Perform calculations of grounding electrode resistance using methods outlined in IEEE Std 142²⁸. Since soil resistivity at LANL ranges from 1,800 to 140,000 Ohm-cm within one mile²⁹, the design professional must investigate and determine the soil resistivity for each site.³⁰ *A recommended method is to have soil resistivity measurement part of the geotechnical report, using the Wenner four-electrode method and procedures described in ASTM G57.*
- C. Install a ground grid under outdoor substations and unit substations to limit touch and step potentials. Comply with requirements in the NESC and IEEE Std 80.

2.2.1 Enclosure and Equipment Grounding

- A. Install an NRTL-listed equipment ground bar or ground lug in each item of electrical equipment and bond it to the equipment enclosure.³¹
- B. Install a 600 volt insulated (green) equipment ground conductor in each raceway.³² *An equipment grounding conductor is not required in a service entrance raceway if the service includes a system grounded conductor.*

²⁴ 25 Ohms is the maximum ground electrode resistance for a made electrode in the NEC.

²⁵ 5 Ohms is indicated in clause 4.1.2 of IEEE Std 142-1991 as suitable ground electrode system resistance for industrial plants and large commercial installations.

²⁶ 1 Ohm is indicated in clause 4.1.2 of IEEE Std 142-1991 as suitable ground electrode system resistance for large industrial plants, substations, and generating stations.

²⁷ Refer to 096 in IEEE C2-2002.

²⁸ Chapter 4 of IEEE Std 142-1991 describes methods for calculating ground electrode resistance.

²⁹ In 1999 soil resistivity measurements were made at LANL using the Wenner Four-Point method on roughly a one-mile grid. Measurements at the 4-ft depth ranged from 2,100 to 93,000 Ohm-cm. There was no consistent relationship of soil resistivity to location.

³⁰ Clause 4.1.3 in IEEE Std 142-1991 strongly recommends that the resistivity of the earth at the desired location of connection be investigated.

³¹ A listed ground bar or ground lug provides an acceptable place to terminate the equipment grounding conductor(s). In many instances at LANL mounting screws or sheetmetal screws have been used to terminate equipment grounding conductors; thus creating potential electrocution hazards.

³² Installation of an insulated equipment-grounding conductor is recommended practice in clause 8.5.3 of IEEE Std 1100-1999. Clause 2.2.3 of IEEE Std 142-1991 indicates that the use of a metal raceway as a grounding conductor supplemented by an equipment grounding conductor achieves both minimum ground fault impedance and minimum shock hazard voltage.

2.3 Duct Bank Grounding

- A. Install a No. 4/0 AWG bare copper ground cable centered in the concrete envelope of each power and telecommunications duct bank. This is in addition to equipment ground conductors that may be installed within the ducts. Connect to manhole grounds and equipment grounds. *This requirement does not apply to concrete-encased underground low-voltage services, feeders, or branch circuits.*
- B. Use materials and installation methods described in LANL Master Specifications Section 33 7119, *Electrical Underground Ducts and Manholes*.

2.4 Fence Grounding

- A. Ground permanent metallic fences crossed by overhead power lines at every third post for a distance of 50 ft from the crossing.³³ *Chain link or metal security fences with steel posts set in concrete may be considered as adequately grounded.*
- B. Bond the gate posts on both sides of every gate opening by the use of direct buried #4/0 copper conductor.³⁴ Bond gateposts to gates with a flexible braided copper conductor. Ground the posts on both ends of gates. *Steel posts set in concrete may be considered as adequately grounded.* This requirement for bonding gate posts applies whether the fence is crossed by power lines or not.
- C. Ground metal fences surrounding substations and switching stations to the station ground system in accordance with the NESC³⁵ and IEEE Std 80.³⁶

³³ Adequate grounding of fences will limit touch, step, and transferred voltages and will promote high-speed fault clearing by overcurrent devices should an overhead power line fall on the fence.

³⁴ Bonding across gate openings and bonding gates will limit touch potential should the fence become energized by a power line or lightning.

³⁵ Refer to 092.E in the NESC (IEEE C2-2002).

³⁶ Refer to 17.3 and 17.4 in IEEE Std 80-2000.

ENDNOTES: