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D5020 LIGHTING & BRANCH CIRCUIT WIRING

New in this revision (older revisions addressed in Record of Revisions at the end)

Added Purpose/Scope. Numerous other changes throughout. Incorporated VAR-2014-046, Non-Powered Exit Signs; VAR-10183, Allowance for multi-wire branch circuits; VAR-10139, Dedicated Equipment-grounding Conductors and Raceways, and VAR-10548, Elimination of Restrictions on Flexible Cords and Cables. Removed requirement to perform life cycle cost analysis for LED luminaires. Removed requirements for special computer receptacles and combined into general-purpose receptacles. Added requirement to use European voltage transformers to supply European equipment. Adjusted requirements for the size of motor that can be started on a transformer. Removed locations of where GFCIs are required when the requirement is already in NFPA 70.
Added Requirements ID Log references (LANL internal-use log posted with chapter)

1.0 PURPOSE AND SCOPE

A. D5020 addresses the electrical system downstream of the final panelboards. The portion of the building's electrical system that supplies the panelboards, and the panelboards themselves, is covered by Section D5010.

B. If an in-scope subject is not explicitly covered by this document, then the requirements of national codes and standards are sufficient.

2.0 RACEWAYS AND BOXES

2.1 Raceways

A. Use raceway systems to contain premises wiring systems. *Article 3.4 below pertains to the use of type MC (metal clad) cable.* (Requirement 7-0001)

B. Indicate sizes of branch circuit raceways on the design drawings and any changes on the record as-built drawings. (Requirement 7-0002)

C. In addition to locations required by the NEC, require conduit sealing with identified sealant at the following locations:

1. Where conduits cross the boundary of a radiological area. (Requirement 7-0003)
2. Where conduits pass between areas where air pressure differential must be maintained. (Requirement 7-0004)
3. Where conduits enter an enclosure protected by a clean agent total flooding fire suppression system. (Requirement 7-0005)

D. Refer to LANL Master Specification Section 26 0533, *Raceways and Boxes for Electrical Systems,* for additional guidance.

E. Use surface metal raceway where there is a high density of receptacles such as at laboratory benches and in computer server rooms. Use surface metal raceway with internal divider(s) to maintain separation between power and telecommunications conductors. (Requirement 7-0006)

1. Use base, covers, and fittings, designed by the manufacturer to be assembled together.

F. Unless in an ITE[1] room, raceways, boxes, and fittings used under raised floors (e.g., computer rooms, server rooms) must have low flame spread, low smoke, and zero halogen characteristics determined in accordance with ASTM E 162 – *Standard Test method for Surface Flammability of Materials Using a Radiant Heat Source*, ASTM E 662 – *Standard Test Method for Optical Density of Smoke Generated by Solid Materials*, or Bombardier SMP-800C- *Toxic Gas Generation*. (Requirement 7-0007)

2.2 Flexible Conduit

A. Use flexible metal conduit for connections to vibrating or moving equipment; use liquid-tight flexible metal conduit for such connections in damp or wet locations or where deteriorating agents may be present such as in some parts of mechanical rooms. Minimum length shall be 18 inches, maximum length per the NEC. (Requirement 7-0008)

1. Where flexible raceways are used for the convenience of installation, not for vibration or movement, the 18-inch minimum length requirement does not apply.

B. Refer to LANL Master Specification Section 26 0533, *Raceways and Boxes for Electrical Systems*, for additional guidance.

2.3 Boxes (Requirement 7-0009)

A. Coordinate locations of outlet boxes with furniture and equipment, to the extent known during design.

B. Design the branch circuit distribution system for permanent, stick-built, office buildings using a modular grid of junction boxes containing the "homerun" circuits for lighting and general-power to allow partition walls to be added or removed with a minimum of interruption to existing outlets.

C. Refer to LANL Master Specification Section 26 0533, *Raceways and Boxes for Electrical Systems*, for additional guidance.

3.0 CONDUCTORS AND CABLES

3.1 Wiring Color Codes (Requirements 7-0010, 11)

A. For new buildings, identify all branch circuit conductors (phase, line, grounded, and grounding conductors) using color-coding that is consistent throughout the building.[2] For work[3] in existing facilities where a consistent color code exists, use wiring color codes to match existing color codes as long as NEC requirements for identifying grounded and grounding conductors are met;[4] if a consistent color

1 Information Technology Equipment rooms, meeting the requirements of NFPA 75 and NFPA 70 Article 645
2 Color coding of phase, or line, conductors facilitates wiring system voltage identification and the correct installation of equipment requiring a specific phase sequence or phase rotation.
3 Refer to ESM Chapter 7, D5000, "Application of this Chapter" heading.
4 Refer to NEC Sections 200.6 and 250.119.

code does not exist in the building, obtain direction from the electrical standards POC on how to proceed.

B. Refer to LANL Master Specifications Section 26 0519, *Low Voltage Electrical Power Conductors and Cables*, for the wiring color codes and for additional guidance.

C. Use the following color codes for AC power system conductors for new installations:

Conductor	480Y/277V	208Y/120V	208Y/120V Isolated Ground*
Phase A	Brown	Black	Black
Phase B	Orange	Red	Red
Phase C	Yellow	Blue	Blue
Grounded (Neutral)	Gray	White	White
Equipment Grounding	Green	Green	Green
Isolated Ground	---	---	Green/Yellow
Switched	Purple or color of feeding circuit with labels: S1, S2…	Pink or color of feeding circuit with labels: S1, S2…	---

* isolated grounds may only be used with the approval of the LANL Electrical Standards Point of Contact

Caution: The rotation of a system might require conductors to be swapped in some locations. This will result in colors that are out of the normal sequence, e.g., Orange/Brown/Yellow instead of Brown/Orange/Yellow. This is acceptable.

1. Use the following color codes for DC power system conductors:

   Positive: Red
   Negative: Black

2. Use the following color codes for 120/240-volt AC, single-phase systems:
   Note: Single phase 120/240 volt systems do not have phases. The

ungrounded conductors are referred to as "line conductors." That is why they do not appear in the above table.

Line 1: Black

Line 2: Red

Grounded Conductor: White, or as permitted by NFPA 70

Equipment grounding conductor: Green, or as permitted by NFPA 70

3.2 Building Wire and Cable

A. Indicate the number and size of conductors in raceways and cable tray sections on the design drawings, and any changes on the record as-built drawings. (Requirement 7-0012)

B. Use copper conductors, AA-8000 series aluminum conductors[5], or copper-clad aluminum[6] for branch circuit wiring.

C. Use minimum No. 12 AWG for branch circuit wiring, for copper conductors. (Requirement 7-0013)

D. Design branch circuit conductors for 3 percent maximum voltage drop at full-design load. The maximum total voltage-drop for both the branch circuit and the feeder should not exceed 5%. Use voltage-drop calculation methods outlined in NFPA70 Chapter 9 Table 9 Note 2. (Requirement 7-0014)

E. Do not use multi-wire branch circuits for laboratory spaces that might supply sensitive laboratory equipment. (Requirement 7-0015)

F. In areas where the total integrated gamma dose for the useful life of the facility is calculated to be 10^6 rads or greater, such as hot cells, use conductor insulation such as cross-linked copolymer, polyvinyl chloride, or polyethylene. Radiation doses will be specified in the project design criteria.[7] (Requirement 7-0016)

G. *Guidance: When following IBC 2015 (ASCE 7-10), raceways 2 inches and smaller are exempt from seismic design.[8] (ref. ESM Ch. 5 Structural, Section II re SDC at LANL). For this reason, it is more cost effective to use 2 inch and smaller raceways wherever possible, should that apply. This typically equates to using 3/0 or smaller conductors, or a 200-ampere circuit. Consideration should be given to running parallel conductors for circuits larger than 200 amps to keep the raceway size 2 inches or smaller. Also, if the use of aluminum conductors increases the size of the raceway to larger than 2 inches, it might be more cost effective to run copper conductors. For trapeze hangers with multiple raceways, consult with structural for direction.*

[5] The New Mexico Electrical Code limits the use of aluminum conductors to those 8 AWG and larger.
[6] Cooper-clad aluminum is considered aluminum for the sake of sizing requirements in NFPA70
[7] Gamma radiation can cause deterioration of the physical and electrical properties of polymers used in conductor insulation materials. Refer to IEEE 1205, *IEEE Guide for Assessing, Monitoring, and Mitigating Aging Effects*.
[8] ASCE7 13.6.5.6 Exception 2

H. Refer to LANL Master Specification Section 26 0519, *Low Voltage Electrical Power Conductors and Cables*, for additional guidance.

3.3 Remote Control Wiring

A. Comply with NEC Article 725.

1. Install life safety, safety-class, safety-significant, and other critical remote-control wiring in raceway systems. (Requirement 7-0017)

2. *Non-critical Class 2 and Class 3 remote control wiring, such as room thermostat wiring in office buildings, may be installed exposed above lift-out ceilings, when the installation meets all applicable Code requirements.*

B. Class 1, non-power limited, and safety-related remote -control wiring:

1. Use stranded copper conductors with 600V THHN/THWN-2 insulation. Within enclosures, conductors with SIS insulation are often used for flexibility. (Requirement 7-0018)

2. Terminate wiring using crimp-on ring tongue or pin-type lugs as appropriate for the terminal.[9] (Requirement 7-0019)

C. Class 2 and Class 3 remote control wiring:

1. For communications circuits, see Chapter 18 of the Engineering Standards Manual. For secure communications, see Chapter 19.

2. Install Class 2 and Class 3 remote control wiring in separate raceways from line voltage and Class 1 circuits. (Requirement 7-0020)

3. Ground cable shields at the controller end; insulate cable shield at the field device end. (Requirement 7-0021)

D. Install remote control wiring without splice or tap from wiring terminal to wiring terminal. (Requirement 7-0022)

E. Label remote control wiring as indicated on the drawings. Use the same label on both ends of the cable, as indicated on the drawings. In the absence of drawings, use a logical label that denotes the function of the cable. Individual conductors within a cable may not need to be labelled, if the functions of each conductor are evident by the application. (Requirement 7-0023)

F. Refer to LANL Master Specification Section 26 0553, *Identification for Electrical Systems*, for guidance.

3.4 Metal-Clad Cable (Type MC) (Requirement 7-0024)

A. *In IBC Group B, F2, I, M, S, or U occupancies, Type MC cable may be used for branch circuit wiring systems. Type MC cable may be used for feeders in these occupancies with the permission of the LANL electrical standards POC.*

[10] Receptacles and receptacle outlets are defined in NFPA 70 Article 100. A receptacle is the device itself and the receptacle outlet is the wiring where a receptacle (or multiple receptacles) is connected.

B. Homeruns: For branch circuits supplying multiple outlets, use conduit or tubing from the first outlet or junction box to the panelboard.

C. Protection: Use of Type MC is limited to interior, dry locations where it will be concealed above suspended ceilings, in dry-wall partitions, in equipment enclosures, or below raised floors. Type MC may be installed exposed in dedicated electrical rooms and mechanical rooms if not be exposed to physical damage or deteriorating agents.

D. Size: Use 12 AWG minimum conductor size.

E. Refer to LANL Master Specification Section 26 0519, *Low Voltage Electrical Power Conductors and Cables*, for additional guidance.

3.5 Flexible Cords and Flexible Cables

A. This article only applies to flexible cords and flexible cables that are installed. It does not apply to equipment cords, power supply cords, or cordsets.

B. Use flexible cords, flexible cables, and their associated fittings that are NRTL-listed and suitable for the conditions of use. Consider temperature, operating voltage, and exposure to moisture, oils, chemicals, sunlight, ozone, and physical abrasion in selecting flexible cords and flexible cables. (Requirement 7-0025)

C. Use flexible cords and flexible cables where permitted by NFPA 70 Article 400, Article 590, or approved by the LANL Chief Electrical Inspector.

D. Flexible cords and flexible cables used at LANL shall be limited to the "hard service" cords, "junior hard service" cords, and "portable power" cables listed in NEC Table 400.4, unless approved by the LANL Chief Electrical Inspector. (Requirement 7-0026)

E. Flexible power cords used under raised floors in ITE rooms (NFPA 75) must be Type DP in accordance with UL 1690 – *Standard for Data Processing Cables*. (Requirement 7-0027)

4.0 WIRING DEVICES

4.1 Receptacles and Receptacle Outlets[10]

A. Design receptacle outlets at locations required and in sufficient density to minimize or eliminate the use of extension cords. (Requirement 7-0028)

B. Show receptacle outlets on the design drawings and any changes on the as-built drawings.

C. 50% of receptacles, in specific locations, may need to be connected to a controlling system that will shut them off, either by a timeclock, a motion sensor, or some other means.[11] (Requirement 7-0082)

[10] Receptacles and receptacle outlets are defined in NFPA 70 Article 100. A receptacle is the device itself and the receptacle outlet is the wiring where a receptacle (or multiple receptacles) is connected.

[11] ASHRAE/IES Standard 90.1 8.4.2

D. Provide 125-volt, 15- or 20-ampere, general-purpose duplex receptacles connected to 20-ampere circuits at the locations described below, at locations required by the NEC, and at locations dictated by the User's functional and operational requirements. Use a unit load of 180 VA per general-purpose receptacle strap when the load is unknown. When the load is known, use the actual load. Refer to Figure D5020-2 for computer loads. (Requirement 7-0029)

1. Hard-wall-enclosed offices, conference rooms,[12] copy rooms, laboratories, and similar spaces: One receptacle outlet on each wall plus additional receptacle outlets so that no point measured horizontally in any wall space is more than 6 ft. from a general-purpose receptacle.[13]
2. Open-office workstations: One receptacle outlet plus additional receptacle outlets so no point measured horizontally in any wall panel space where equipment may be located is more than 6 ft from a general-purpose receptacle.
3. Laboratory countertops: At least one receptacle outlet for each 3 ft. of countertop.[14]
4. Kitchens and break rooms: In addition to known loads such as microwaves, water heaters, ice makers, vending machines, and garbage disposals, at least one receptacle outlet on each wall where not used for counters.
5. Equipment rooms: At least one receptacle outlet plus additional receptacle outlets so all equipment that may require maintenance is within 25 ft. of a receptacle. At least one receptacle for building automation equipment. *See requirement below for GFCI receptacles in mechanical equipment rooms.* (Requirement 7-0030)
6. Corridors: 20-ampere receptacle outlets on individual branch circuit(s) for custodial use located so no point on any corridor floor is more than 25 ft from a receptacle.[15]
7. Copy rooms: One receptacle outlet on each wall plus additional receptacle outlets so no point measured horizontally in any wall space is more than 6 ft. from a general-purpose receptacle. At least one receptacle outlet for each 3 ft. of countertop or fraction thereof for small office equipment such as printers. At least one 20 ampere receptacle on an individual branch circuit for a copy machine. *Some copy rooms may have high-capacity printers requiring higher-capacity circuits*.

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12 Conference rooms have special requirements in NFPA 70. NFPA 70-2017 Section 210.71 or NFPA 70-2020 Section 210.65. They are the same wording; the 2020 Code just moved it to a new location.

13 Receptacle spacing is based on the 6-ft cords supplied with most electrical equipment used in offices. Adequate accessible receptacles will reduce or eliminate the need for extension cords.

14 3-ft spacing of receptacles at lab workbenches provides a reasonable capacity for general bench-top laboratory equipment.

15 Power cords on commercial vacuum cleaners are typically 30 ft or longer. The 25-ft requirement is to prevent excessive mechanical strain on plugs and receptacles. The 20-amp receptacles are to accommodate floor buffers and carpet cleaning equipment.

Figure D5020-2 PC Workstation Loads

PC Workstation Equipment	Average Measured Current (Amps)	Unit Load (Volt-Amps)	Feeder/Service Demand Factor
Computer	1.7	200	100%
Monitors (two)	1	120	100%
Printer[16]	0	450	0%
Load for Workstation		320	100%

8. For computer or instrument circuit receptacles not connected to SPD-protected circuits, use UL 1449 (*Standard for Surge Protective Devices*) listed relocatable power taps to supply the equipment; however, 125 volt, 15- or 20-ampere, surge-suppression-type duplex receptacles are also acceptable.[17]

E. Provide 125-volt, 15 or 20-ampere duplex ground-fault circuit-interrupter (GFCI) type receptacles[18] at the locations listed below, locations required by the NEC, and at locations dictated by the user's functional and operational requirements. Use a unit load of 180 VA per GFCI receptacle strap unless noted otherwise. Locate GFCI type receptacles so they will be accessible for monthly testing[19] after equipment and user-supplied appliances are in place. Where it is not practical to make GFCI type receptacles accessible (e.g., behind vending machines), install non-GFCI receptacles and supply them from GFCI circuit breakers; label the receptacles "GFCI Protected."

1. Outdoor locations, including roofs: At least one receptacle outlet within 25 ft. of mechanical equipment that may require maintenance.[20, 21] For gas meters and pressure regulators, locate receptacle outlets at least 3 ft. away.[22] (Requirement 7-0031)
2. Outdoor locations: At least one receptacle outlet within 6 feet of each personnel and vehicle entrance plus additional receptacle outlets so no point measured horizontally on the building perimeter is more than 80 ft. from a receptacle.[23]
3. Laboratory and experiment areas: Any receptacles located within 6 feet of the outside edge of a sink. (In addition, at least one receptacle in each laboratory must be non-GFCI protected.) (Requirement 7-0032)

16 Most printers are operating for a very short time. As such, they do not contribute appreciably to the overall load.
17 Section D5010 establishes 30 outlets as the point for providing a panel-mounted SPD; for less than 30 outlets, SPD-type receptacles, or the use of relocatable power taps, are a more economical alternative.
18 GFCI receptacles are usually more economical and more reliable than GFCI circuit breakers, especially on long branch circuits. Having a reset button at the point of use, when possible, makes it easier on the user to reset in case of a trip.
19 NEC Section 210.8 requires that ground-fault circuit interrupters be readily accessible.
20 Uniform Mechanical Code, 2000 Edition, paragraph 309.0 requires a receptacle within 25 ft. of mechanical equipment.
21 NEC section 210.8(B) requires GFCI protection.
22 NFPA 54 *National Fuel Gas Code* Chapter 5.
23 80-ft receptacle spacing allows a 100-ft cord to reach all points within 60 ft of the building exterior.

4. Laboratory, experiment, battery, and chemical areas: Any receptacles located within 6 feet of an emergency shower/eyewash station.
5. Kitchen/break areas: At least two receptacle outlets serving the countertop area(s). Provide at least one receptacle outlet for each countertop space that is 12 inches or wider.[24] Provide receptacle and 20-amp individual branch circuit for each vending machine. Design distribution system using a unit load of 1500 VA per circuit for the kitchen circuits and a load of 750 VA for the vending machine circuits.[25]
   Note: New vending machines come with GFCI protection built into the power supply cord.
6. Bathroom, locker room, and shower areas: At least one above-counter receptacle outlet within 36 inches of each lavatory bowl. At least one below lavatory counter to supply power supplies for proximity-sensing electronic faucets and flush valves. In high-use locations, such as a wellness center or gym, additional circuits should be provided where simultaneous loads, such has hair dryers, are expected to be used.
7. Janitor closets. At least one receptacle outlet.[26]
8. Receptacle outlets for vending machines not in kitchen or break areas. For each vending machine, provide a receptacle outlet connected to a 20-amp individual branch circuit; for load calculations use a unit load of 750 VA per vending machine.
   Note: New vending machines come with GFCI protection built into the power supply cord.
9. Static-grounded areas: Provide receptacle outlets to meet the user's functional and operational requirements.[27]
10. Electric drinking fountains: Provide receptacle outlet(s) connected to 15-amp, or 20-amp, individual branch circuit(s); for load calculations use a unit load of 480 VA per electric drinking fountain.[28]

F. For portions of facilities (e.g., fire stations) that are designated by the *International Building Code* as Group R Residential, comply with NEC requirements for receptacle outlets and circuit protection in "dwellings."

G. Coordinate receptacle locations with furniture and equipment layout, to the extent known during design, so receptacles will be accessible.

1. In common areas (e.g., conference rooms, break rooms) install receptacles (and telecommunications) with center approximately 18 inches above the finished floor.[29] Locate receptacles to comply with

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[24] NEC Section 210.52(C) is extended to non-dwelling occupancies.
[25] Unit load for receptacle outlets in kitchen and break areas is to adequately serve User-supplied vending machines, coffee makers and microwave ovens.
[26] Outlet is to serve battery chargers for battery-powered janitorial equipment.
[27] The DOE Explosives Safety Manual, paragraph 7.8, recommends GFCI receptacles in static grounded areas.
[28] GFCI protection of electric drinking fountains is required by NEC section 422.52. Unit load is from typical EWC vendor's catalog data.
[29] Height complies with *ADA Accessibility Guidelines for Buildings and Facilities* (ADAAG), (28CFR, Ch 1, Part 36, App A) available at http://www.access-board.gov/adaag/html/adaag.htm.

Americans with Disabilities Act Accessibility Guidelines (ADAAG), 28 CFR Part 36, Appendix A.

2. Locate wall mounted receptacles (and telecommunications) in hard-wall-enclosed offices with center approximately 7" above the finished floor (immediately above the cove base).[30, 31] Coordinate locations of receptacle outlets with modular furniture and associated hangers such that receptacles will be accessible.[32]
3. Coordinate mounting height of receptacles at lab benches and counters with architectural details. The maximum height to meet ADAAG requirements is 44 inches.

H. Group power and communications outlets so a symmetrical appearance results.

I. Select and design heavy-duty receptacles as follows:

1. If an appliance or equipment item is supplied with an attachment plug that is suitable for the application and location, specify a receptacle to match the attachment plug.
2. If the appliance or equipment item is not supplied with a suitable attachment plug, specify a suitable attachment plug and matching receptacle.
3. For a 480 volt or 480Y/277-volt receptacle that is out of sight, or more than 50 ft from a lockable circuit disconnect, use a receptacle with an interlocked circuit disconnect to prevent insertion or removal of a plug while the receptacle is energized.[33]

J. Provide receptacles for electric welders in mechanical equipment rooms where maintenance or future modification of piping or equipment may require welding. Consider receptacles for electric welders in process equipment rooms, laboratories, and similar spaces where maintenance or future modification of piping or equipment may require welding.[34]

1. Density: At least one receptacle per 1800 sq. ft. or fraction thereof; provide and locate receptacles to be within 50 ft. cable distance of each item to be welded.
2. Pin and sleeve receptacle: 480 volts, single phase, 2-pole, 3-wire, 100 amperes unless otherwise required by the User.
3. Local disconnect: 3-pole fusible switch supplying welding receptacle, or pin and sleeve receptacles with built-in disconnects.
4. Circuit rating: Per NEC Article 630.

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30 Office spaces with special ADAAG accommodations will be provided on an as-needed basis.
31 The 7" center mounting height will allow the receptacle device plate to be completely above a 4" cove base and below furniture "modesty panels" that are typically 9-1/4" Above Finished Floor.
32 Lesson learned from LANL construction projects.
33 IEC pin and sleeve receptacles provide more positive voltage class indication than NEMA configured devices. They can be safely plugged and un-plugged at full rated voltage and current.
34 Lesson learned from CMRR RLUOB project.

5. Circuit source: Panelboard or switchboard that does not supply noise-sensitive loads.

K. Connect receptacles to branch circuits as follows:

1. Connect a maximum of eight general-purpose duplex receptacles per 20-amp circuit.[35]
2. Connect laboratory glovebox, fume hood, and bench top receptacles as follows:
   - Where loads that will be connected to receptacles are known, design branch circuiting based on the loads.
   - In experimental facilities where loads to be connected to receptacles are not known, connect a maximum of four receptacles per 20-amp circuit.[36]
   - In production facilities where loads to be connected to receptacles are not known, connect up to 8 receptacles per 20-amp circuit.

L. Refer to materials and installation methods described in LANL Master Specifications Section 26 2726, *Wiring Devices*.

4.2 Receptacle Plates (Requirement 7-0033)

A. For flush mounted receptacles use brushed 302/304 alloy stainless steel plates, or as requested by the architect.[37]

B. For surface mounted receptacles use galvanized steel, to match installation.

C. For flush mounted interior receptacles connected to special power systems to serve computers and other equipment processing secure information, use red colored smooth plastic plates.[38]

D. Refer to LANL Master Specifications Section 26 2726, *Wiring Devices,* for additional guidance.

E. Refer to LANL Master Specifications Section 26 0553, *Identification for Electrical Systems,* for guidance on labeling receptacle cover plates.

5.0 WIRING CONNECTIONS

5.1 General

A. Make power, control, and interlock connections to electrically operated equipment in accordance with the NEC and the equipment manufacturer's instructions.

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35 Historical limit for LANL. Not driven by any Code. "General Purpose" here means available for cord-and-plug connected loads. If the circuit contains receptacles, but is dedicated to a function like lighting, and has no receptacles that are available for unknown cord-and-plug connected loads, this requirement does not apply.

36 Based on lessons learned from the CINT projects; users experienced circuit breaker trips in labs with eight duplex receptacles per circuit.

37 Stainless steel plates provide greater durability than other materials.

38 This method cost-effectively identifies outlets intended for "RED" (secure) processing equipment.

B. Use materials and methods described in Sections D5000, D5010, and D5020 of this chapter and suitable for the installation location and environment. (Requirement 7-0034)

C. Install receptacles, disconnect switches, motor controllers, and control devices to complete the equipment wiring connections.

D. Design dedicated power circuits for building automation systems and related control system components. (Requirement 7-0035)
Note: "dedicated" does not mean "individual branch circuit." Dedicated means the branch circuit, regardless of the number of outlets or receptacles, is dedicated to the building automation system.

E. Some specialized, non-domestic, and possibly non-NRTL-listed laboratory equipment will require power with different characteristics (e.g., voltage, frequency) than that which is available in the facility.

Equipment that requires three-phase power shall be supplied by a transformer rated for the equipment voltage. *Transformers are available that have an American voltage primary (e.g., 208 or 480) and have a European voltage secondary (400/230).* Buck/Boost transformers shall not be used for supplying three phase European equipment.[39]

Equipment that requires single-phase power shall be supplied by a transformer in the same configuration as the equipment. Equipment that requires 230 volts single phase may be supplied by a buck transformer connected to a 277-volt circuit. Boost transformers shall not be used to convert 208 (Line to Line voltage) to 230 (Line to Neutral voltage). 230-volt equipment shall not be directly connected to 208 volts.

Non-NRTL-listed laboratory equipment, special power conversion apparatus (e.g., special transformers, frequency converters, buck-boost transformers), and their installation must be approved by the LANL electrical standards POC.[40] (Requirement 7-0036)

F. Show locations, sizes, and configurations of equipment connections on the design drawings. Record changes to locations, sizes, and configurations of equipment connections in the project record documents.

5.2 Skid-Mounted Equipment Assemblies

A. Design and specify skid-mounted equipment assemblies to comply with and be NRTL-listed to NFPA 79 – *Electrical Standard for Industrial Machinery*,[41] if applicable.

[39] Using buck/boost transformers might technically work but they create a system that is unusual to the worker. Discussions with the electrical safety committee and the Chief Electrical Safety Officer have resulted in the decision to not allow these systems for new installations.
[40] Refer to Chapter 5 in LANL P101-13, *Electrical Safety Program*.
[41] Refer to NEC Article 670 and NFPA 79.

6.0 MOTORS AND MOTOR CONTROLLERS

6.1 Motor Controllers (Requirement 7-0037)

A. Provide a NEMA-rated controller for each three-phase motor that does not have an integral controller or is not controlled from a motor control center.

1. Custom-fabricated motor control panels must be NRTL-listed[42] to UL 508A *UL Standard for Safety Industrial Control Panels.*
2. *Starters and related control devices in factory assembled control systems may be IEC type with IEC 947-4-1 type-2 coordination.*

B. Use motor controllers as follows to limit voltage dips to acceptable levels: [43]

1. Full-voltage starting may be used for motors with horsepower rating not exceeding 25 percent of the upstream transformer's base (self-cooled) kVA rating.
   Note: This assumes an unloaded transformer. For loaded transformers, allow 4 times the HP rating of the motor in transformer kVA in addition to the load on the transformer. Example: a 150 hp motor should have 600 kVA transformer capacity to efficiently start the motor.
2. Use reduced voltage starting (Solid-state "soft start," or variable speed drive) for motors with horsepower rating exceeding 25 percent of the upstream transformer's base (self-cooled) kVA rating.
3. If a motor will be supplied by a standby or emergency power system, use reduced voltage starting (Solid-state, or variable speed drive) if the horsepower rating exceeds 25 percent of the available capacity of the generator kVA rating.
4. Provide motor controllers having a UL 508 short circuit withstand rating that exceeds the fault current available at the controller line terminals.[44] (Requirement 7-0038)

C. Use a control voltage of 120V or less.[45] Refer to "Remote Control Wiring" in Section D5020 for additional requirements.

D. Provide LED type indicator lights on the front of each magnetic controller.[46] Indicating lights shall be color-coded and labeled to clearly identify the operational mode of the equipment or system. *Refer to drawing ST-D5020-1 for pilot light connections. Pilot lights in integrated motor controller interface modules may be used as supplied.* For discrete pilot lights use the following indicator light color code:[47]

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42 Refer to chapter 5 of LANL P101-13 *Electrical Safety Program*.
43 Criteria for motor starting from Chapter 3 of IEEE Std 141.
44 Required by NEC Section 110.9.
45 Use of 120V control power provides a greater degree of safety than line voltage control power. Some equipment manufacturers use much lower voltage control power.
46 LED pilot lights are more reliable and require less maintenance than incandescent pilot lights.
47 Pilot light color codes of RED for "running" and GREEN for "stopped" or "off" are commonly used in motor controllers for building systems.

1. RED (Danger/Hazard) denotes a system or component that is energized, running, or closed.
2. GREEN (Normal/Safe) denotes a system or component that is de-energized, stopped (not running), or open.
3. AMBER (Caution/Standby/Pending Trouble) denotes a fault condition.

Note that other pilot light color codes are used on control panels for industrial machinery built to NFPA 79 or in process systems that are built to ISA Standard 5.5.

E. Provide start-stop switch function on the front of each magnetic controller not connected to automatic controls. Arrange control circuit to include emergency stop functions, such as fire alarm interlocks.

F. Provide selector switches on motor controllers for the purposes of testing and troubleshooting equipment, or manually controlling the equipment should the automatic control system fail.

1. In general, provide a HAND-OFF-AUTO (H-O-A) selector switch or ON-OFF-AUTO switch function on the front of each magnetic controller connected to automatic controls. *Refer to LANL Standard Drawing ST-D5020-1 for selector switch connections.* Arrange control circuit to accomplish the following operating sequences:
   - With the selector switch in the HAND or ON position the motor runs. Emergency stop functions, such as fire alarm interlocks, are in effect.[48]
   - With the selector switch in the AUTO position the motor is controlled by the external automatic control system. Emergency stop functions, such as fire alarm interlocks, remain in effect.
   - With the selector switch in the OFF position the motor is stopped, and the external automatic control system will not control the motor.
2. Some applications, typically controlled by a building automation system (BAS) or a programmable logic controller (PLC), have critical interlocking or complicated sequencing requirements that preclude the use of conventional H-O-A switches with the individual motor controllers. Address such cases as follows:
   - Where feasible, use hard-wired interlocks between the individual motor controllers of the system, and provide a system level HAND-OFF-AUTO (H-O-A) selector switch.
   - Where hard-wired interlocks are not feasible, use administrative controls and a system of key interlocks applied to motor controller selector switches to ensure operation of the equipment in the required sequence.

[48] These emergency stop functions make the Hand position an inappropriate zero-energy test for mechanical LO/TO. This necessitates a local disconnect for LO/TO.

- Where interlocks or administrative controls are either not feasible or not permitted (e.g., safety instrumented systems), local selector switches may be omitted.

G. *Some applications may warrant a highly visible EMERGENCY OFF mushroom head stop button on the face of the controller. Emergency off switch function should be a maintained switch action with either turn-to-release, pull to release, or key-unlock release to ensure that automatic controls will not re-start the motor.*

H. For three phase motor starters supplying motors with full load current up to and including 300 amperes, provide solid state motor starter overloads.

I. For motor starters supplying low-voltage motors with full load current over 300 amperes, or medium-voltage motors, provide a solid-state motor protective relay with the following characteristics:

1. Thermal overload protection; IEEE C37.2 function number 49
2. Locked rotor protection; IEEE C37.2 function number 51.
3. Phase fault protection; IEEE C37.2 function number 50.
4. Ground fault protection; IEEE C37.2 function number 50G/51G
5. Current unbalance protection; IEEE C37.2 function number 46.
6. Load jam protection; IEEE C37.2 function number 48.
7. Load loss protection; IEEE C37.2 function number 37.
8. Stator winding temperature with RTDs, alarm or trip; IEEE C37.2 function number 49.
9. Motor bearing temperature with RTDs, alarm or trip; IEEE C37.2 function number 38.
10. Starts per hour limit; IEEE C37.2 function number 66.
11. Selectable manual or automatic reset.
12. Display of motor phase current and ground current.
13. Display of number of starts and run time.
14. Display of trip type.
15. Current sensing using external current transformers with 5 amp secondary for phase currents and zero sequence ground fault.

J. Except for packaged equipment with integral controllers, do not locate motor controllers above ceilings.[49]

[49] Controllers located in crowded ceiling spaces have often lacked adequate working space to meet requirements in NEC Article 110.

K. Position packaged equipment to obtain the NEC required clearances to integral control equipment.[50]

L. Refer to LANL Master Specification Section 26 2913, *Enclosed Controllers,* for additional guidance.

6.2 Motor Control Centers (Requirement 7-0039)

A. Use motor control centers where the total installed cost will be less than that for individual combination starters. *This is usually when there are more than three 480V motor loads that require controllers.* Avoid using motor control centers for distribution switchgear; switchboards and panelboards are more economical. Where possible, locate motor control centers in mechanical rooms containing the motors supplied.

B. Provide motor control centers with short circuit rating that exceeds the available fault current. (Requirement 7-0038)

C. Provide motor control centers with main bus capable of 20% future load growth. Provide 10% spare starters (not less than one of each designated size) and 10% spare spaces (not less than one) in each motor control center for future use.[51]

D. Refer to LANL Master Specifications Section 26 2419, *Motor Control Centers* for additional guidance.

6.3 Variable Frequency AC Controllers (variable frequency drives)

A. In addition to the requirements for magnetic combination type starters, use the following requirements and guidance for selecting variable frequenc drives (VFDs) supplying induction motors:

1. Use configured VFDs each consisting of an integrated assembly with externally operated disconnect device, current-limiting fuses, line input reactor, power converter, cooling fans, operator interface, control system interface, control power transformer, and a suitable enclosure.

2. Interface VFDs with the building automation system using ANSI/ASHRAE Std 135, ISO 16484-5 approved BACnet-compatible communications.

3. Interface VFDs with process systems using analog inputs with 0-20 mA, 4-20 mA, or 0-4 V, 0-8 V, and 0-10 V parameters and 0-10 V output signal proportional to speed or load as required to interface with control system. (Requirement 7-0040)

4. De-rate VFD capacity, if necessary, to 7500 ft. altitude, 3% to 5% high supply voltage (typical), and high carrier frequency. *These factors often mean that VFD application capability is as low as 75% of drive rated current.* (Requirement 7-0041)

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[50] Motor controllers are likely to require testing or inspection while energized; therefore, NEC section 110.26(A) must be satisfied.

[51] The combination of spare starters and spaces is intended to fulfill the requirement for future 20% growth.

B. Provide VFDs with redundancy as described below:[52]
NOTE: Some safety significant and all safety class systems will have fully redundant trains, making VFD bypasses necessary. (Requirement 7-0042)

1. 3-contactor isolation and bypass system for VFDs supplying loads that are suitable for operation at full speed in safety significant systems without redundancy, life safety systems, and mission critical systems; refer to Electrical Drawing ST-D5020-1 for example control diagram.
2. Dual VFDs with manual transfer switch for VFDs supplying loads that are not suitable for operation at full speed in safety significant systems without redundancy, life safety systems, and mission-critical systems.
3. For other applications, consider the provision of spare VFDs. *Factors to consider are the future availability of suitable replacement drives from vendors and the limited "shelf life" of some components (e.g., electrolytic capacitors) in VFDs that might be purchased as spares.*

C. Locate VFDs at locations that are:

1. Accessible by authorized persons and provide the NEC-required working clearances. (Requirement 7-0043)
2. Supplied with sufficient ventilation/cooling to dissipate the heat from the VFD while maintaining suitable ambient conditions for the VFD. (Requirement 7-0044)
3. Suitable to accept or adequately attenuate the audible noise generated by the VFD. (Requirement 7-0045)

D. Locate PWM-type VFDs as close as practical to the motors they supply. If the distance from the VFD to the motor must exceed 100 ft, or distance indicated by the manufacturer, provide RFI/EMC filters or other means to limit high frequency voltage in the motor windings. (Requirement 7-0046)

E. If a safety disconnect is to be installed between the VFD and the motor, interlock the controller run-permissive circuit using an auxiliary switch in the disconnect. *Note: Safety Switches are sometimes necessary to facilitate LO/TO. Some VFDs are not practical LO/TO points.* (Requirement 7-0047)

F. In addition to the harmonic-mitigating features specified for individual VFDs, provide additional harmonic-mitigating distribution-system components as required to limit harmonic currents and voltages at the point of common coupling to comply with IEEE 519 *IEEE Recommended Practices and Requirements for Harmonic Control in Electric Power Systems.* (Requirement 7-0048)

1. If the total connected kVA of VFDs exceeds 15 percent of the self-cooled kVA rating of the facility utility transformer submit analysis of harmonic distortion at the point of common coupling (PCC).
2. The PCC for voltage distortion shall be at the secondary of the utilization voltage service transformers.

[52] Refer to *Consulting Specifying Engineer*, March 2010 article "Dual VFDs Versus Bypasses: Engineers Weigh In" for a detailed discussion of dual AFCs (VFDs), bypasses, and spare AFCs (VFDs).

3. The PCC for current distortion shall be at the primary of the utilization voltage service transformers.

4. Use analysis procedures outlined in IEEE 519; assume that all connected VFDs are operating at 80% speed.

G. Refer to LANL Specification Section 26 2923, *Variable Frequency Motor Controllers,* for further guidance.

6.4 Manual Starters (Requirements 7-0049, 50)

A. Use 120 VAC single-phase manual motor starters for controlling single-phase fractional horsepower motors where automatic or remote control is not required. (Use magnetic starters for all three-phase motors and for single-phase motors requiring automatic or remote control.)

B. Provide manual switch starters with thermal overload protection for single-phase motors not having internal automatic thermal overload protection or impedance protection.

C. Provide manual motor starters with means for padlocking in the OFF position.

D. Provide each manual motor starter with an LED type red running pilot light.

6.5 Motor Disconnecting Means

A. Install disconnecting means, with a door that can be opened, within sight of each motor and its driven equipment.[53] The raceway between the disconnect and the motor is to be installed so it is completely visible.[54] (Requirements 7-0051, 52)

B. For three-phase motors use heavy-duty type, NRTL-listed, horsepower rated safety switches that meet NEMA KS 1. (Requirement 7-0052)

1. Use non-fused safety switches for typical motor disconnecting applications. For applications where the available short-circuit current exceeds 10,000 amperes, refer to the manufacturer's application data or use fusible safety switches with dual-element Class RK1 fuses, or use enclosed circuit breakers.

2. Some HVAC equipment manufacturers require dual-element fuses as overcurrent protection for their units. Use fused safety switches with dual-element Class RK1 fuses for such equipment.

C. Provide the appropriate NEMA enclosure type for the environment. (Requirement 7-0054)

D. Provide permanently installed padlocking provision for each motor disconnecting means.[55] (Requirement 7-0055)

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[53] Refer to NEC Section 430.102(B). The disconnect is essential for lockout/tagout. Mechanical lockout/tagout needs a reliable place to lockout the circuit. Electrical lockout/tagout requires an absence of voltage test.

[54] This is required for LO/TO. Mechanical LO/TO consists of Lock-Tag-Try. The most reliable means of ensuring zero energy to the equipment is for a local means of disconnect. Electrical LO/TO requires an absence of voltage check. This requires a door that can be opened.

[55] Permanently installed padlocking provisions will facilitate compliance with LANL lock-out/tag-out requirements.

E. Locate disconnecting means, at either the controller or the motor, to be readily accessible.[56] (Requirement 7-0056)

F. Refer to LANL Master Specification Section 26 2816, *Enclosed Switches and Circuit Breakers,* for additional guidance.

6.6 Motor Connections

Use NRTL-listed splicing kits for insulating and sealing connections in terminal boxes of motors rated 1 hp and larger. Provide splicing kits that include a 1 kV dielectric-rated sleeve with thick walls to resist abrasion and puncture.[57] (Requirement 7-0057)

6.7 Motors

A. Use NEMA Premium labeled[58] energy efficient motors for new installations and for replacements of motors. When available, for the application, use motors that comply with IEEE-841. Use motors with minimum efficiencies that comply with Table D5020-3 and are measured according to NEMA Standard MG1 and IEEE Std 112, test method B. Motor nameplates shall contain efficiency labeling per NEMA Standard MG1-12.53b for full-load efficiency with indicated maximum and minimum expected efficiency. Motor nameplate minimum efficiency shall meet or exceed the minimum values in Table D5020-3. (Requirement 7-0058)

B. Select motor rated voltage to economically supply the load, to match building system voltage(s), and to limit voltage dip when starting the motor.[59] (Requirement 7-0059). *Use the following as guidance in selecting motor rated voltages:*

1. *460V, 3-phase motors are preferred for all applications.*
2. *200V, or 208V 3-phase, 60 Hz when 480 volts is not available. Do not use 230V three phase motors.*
3. *4000V, 3-phase for motors 500 HP and larger.*
4. *115V, or 230V, single phase, 60 Hertz for motors smaller than 1 HP, unless in a hazardous classified area where three phase is required, regardless of the size of the motor.*

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56 Requirement in NEC section 430.107 repeated for emphasis.

57 Lesson learned from cooling tower replacement project at TA-53. Motor lead splices insulated with vinyl electrical tape failed after a short time due to abrasion of the tape.

58 The NEMA Premium label program is sponsored by the National Electrical Manufacturers Association (NEMA) and endorsed by the Consortium for Energy Efficiency (CEE). Executive Order 13123 and FAR part 23 direct agencies to purchase products in the upper 25% of energy efficiency. Refer to DOE's Federal Energy Management Program information on NEMA Premium label motors at http://www.eren.doe.gov/femp/procurement/pdfs/motor.pdf.

59 Refer to Chapter 3 of IEEE Std 141.

Table 5020-3 Minimum Motor Efficiency

NOMINAL FULL-LOAD EFFICIENCY						
MOTOR HP	NUMBER OF POLES / SYNCHRONOUS SPEED, RPM					
	ODP MOTORS			TEFC MOTORS		
	2 3600	4 1800	6 1200	2 3600	4 1800	6 1200
1	77.0	85.5	82.5	77.0	85.5	82.5
1.5	84.0	86.5	86.5	84.0	86.5	87.5
2	85.5	86.5	87.5	85.5	86.5	88.5
3	85.5	89.5	88.5	86.5	89.5	89.5
5	86.5	89.5	89.5	88.5	89.5	89.5
7.5	88.5	91.0	90.2	89.5	91.7	91.0
10	89.5	91.7	91.7	90.2	91.7	91.0
15	90.2	93.0	91.7	91.0	92.4	91.7
20	91.0	93.0	92.4	91.0	93.0	91.7
25	91.7	93.6	93.0	91.7	93.6	93.0
30	91.7	94.1	93.6	91.7	93.6	93.0
40	92.4	94.1	94.1	92.4	94.1	94.1
50	93.0	94.5	94.1	93.0	94.5	94.1
60	93.6	95.0	94.5	93.6	95.0	94.5
75	93.6	95.0	94.5	93.6	95.4	94.5
100	93.6	95.4	95.0	94.1	95.4	95.0
125	94.1	95.4	95.0	95.0	95.4	95.0
150	94.1	95.8	95.4	95.0	95.8	95.8
200	95.0	95.8	95.4	95.4	96.2	95.8
250	95.0	95.8	95.4	95.8	96.2	95.8
300	95.4	95.8	95.4	95.8	96.2	95.8
350	95.4	95.8	95.4	95.8	96.2	95.8
400	95.8	95.8	95.8	95.8	96.2	95.8
450	95.8	96.2	96.2	95.8	96.2	95.8
500	95.8	96.2	96.2	95.8	96.2	95.8

C. Do not select motors to operate continuously above rated load in the service factor area (e.g., conditions that exceed nameplate values).[60] (Requirement 7-0060)

D. De-rate motors for operation at 7500 ft. altitude[61] in accordance with Table 5020-4 taking into consideration the ambient temperature of the motor environment. Select motor based on 104 degrees F ambient temperature unless motor is in a moving air stream when operating.

[60] Service factor is an indication of how much overload a motor can withstand when operating normally within the correct voltage tolerances. For example, the standard SF for open drip-proof (ODP) motors is 1.15. This means that a 10-hp motor with a 1.15 SF could provide 11.5 hp when required for short-term use. In general, it's not a good practice to size motors to operate continuously above rated load in the service factor area. Motors may not provide adequate starting and pull-out torques, and incorrect starter/overload sizing is possible.

[61] Motors with a service factor of 1.15 do not have to be de-rated for altitude, per NEMA MG-1

Table 5020-4 Motor Selection Table[62]

Motor Nameplate (hp)	Maximum Motor Shaft Load [e] (bhp) Ambient Temperature [a, b, c] (deg F)					
	81.1	85	90	95	100	104[d]
1	1.00	0.98	0.95	0.92	0.89	0.87
1.5	1.50	1.47	1.43	1.38	1.34	1.31
2	2.00	1.96	1.90	1.85	1.79	1.75
3	3.00	2.93	2.85	2.77	2.68	2.62
5	5.00	4.89	4.75	4.61	4.47	4.36
7.5	7.50	7.34	7.13	6.92	6.71	6.55
10	10.0	9.78	9.51	9.23	8.95	8.73
15	15.0	14.7	14.3	13.8	13.4	13.1
20	20.0	19.6	19.0	18.5	17.9	17.5
25	25.0	24.5	23.8	23.1	22.4	21.8
30	30.0	29.3	28.5	27.7	26.8	26.2
40	40.0	39.1	38.0	36.9	35.8	34.9
50	50.0	48.9	47.5	46.1	44.7	43.6
60	60.0	58.7	57.0	55.4	53.7	52.4
75	75.0	73.4	71.3	69.2	67.1	65.5
100	100	97.8	95.1	92.3	89.5	87.3
125	125	122	119	115	112	109
150	150	147	143	138	134	131
200	200	196	190	185	179	175
250	250	245	238	231	224	218
300	300	293	285	277	268	262
350	350	342	333	323	313	305
400	400	391	380	369	358	349
450	450	440	428	415	403	393
500	500	489	475	461	447	436

Notes:
a. Select motor based on 104 degrees F ambient temperature unless motor is in a moving air stream when operating.
b. Document selection of an ambient temperature lower than 90 degrees F.
c. Do not extrapolate to ambient temperatures below 81.1 or above 104 °F. If the ambient temperature is outside the 81.1 °F to 104 °F range, refer to NEMA MG 1 and/or the motor manufacturer for guidance.
d. If ambient temperature exceeds 104 degrees F, select motor with greater nameplate hp rating in accordance with NEMA MG 1.
e. Motor selection criteria developed from temperature rise considerations in NEMA MG 1-2003, clauses 12.43, 12.51.2, and 14.4.

62 Motor selection table is based on NEMA MG 1-12 with the following assumptions:
a. Motors will not be operated beyond a service factor of 1.0.
b. Effects of ambient temperature on motor temperature rise are linearly interpolated from 81.1 °F (de-rating factor = 1.0) to 104 °F (de-rating factor = 0.8727).
c. Motor operating parameters (e.g., voltage, phase voltage balance) are within normal ranges specified in NEMA MG 1.

E. For motors used with PWM variable frequency drives, provide motors that comply with Part 31 of NEMA MG1. For motors used with six-step adjustable frequency controllers provide motors that comply with either Part 30 or Part 31 of NEMA MG1. (Requirement 7-0061)

F. Refer to LANL Master Specification Section 26 0700, *Induction Motors -500HP and Smaller* for additional guidance.

6.8 Motor Control Diagrams (Requirement 7-0062)

A. Use ESM Standard Drawing ST-D5020-1 as a template for project motor control diagrams.[63]

B. Edit the template to meet project-specific requirements.

C. Indicate field wiring and modifications to factory wiring.

D. *One diagram may be used to represent several identical motor control configurations.*

7.0 GROUNDING AND BONDING

7.1 Enclosure and Equipment Bonding (Requirement 7-0063)

A. Provide a 600-volt equipment grounding conductor of the wire type in each feeder or branch circuit raceway and in each raceway for line voltage control wiring and non-power-limited wiring systems.[64] Size equipment-grounding conductors as required in NFPA 70. (Requirement 7-0124)

B. An equipment grounding conductor of the wire type is not required in raceways for power limited alarm and telecommunications wiring systems; however, metallic raceways must be electrically continuous as required by the NEC.[65]

C. Each piece of equipment that requires the connection of a "grounding conductor"[66] should have a grounding termination bar installed, as follows:

1. A factory installed bar
2. A field installed bar which is an accessory that has been listed with the equipment
3. A field installed bar which is not a listed accessory. In this case, install a bonding jumper from the grounding terminal bar to the enclosure with a bonding jumper that is sized for the conductors feeding the equipment. (Requirement 7-0123)

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63 Refer to ESM Chapter 7 Section D5000 paragraph 4.3-L.

64 Installation of an insulated equipment-grounding conductor is recommended practice in Chapter 8 of IEEE Std 1100. 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.

65 Refer to NEC Sections 300.10, 250.4(A)(3), and 250.4(A)(4)

66 "grounding conductor" in this case could either be an Equipment Grounding Conductor or a Supply Side Bonding Jumper.

D. Refer to LANL Master Specification Section 26 0526, *Grounding and Bonding for Electrical Systems,* for additional guidance.

7.2 Isolated Grounding System (Requirement 7-0064)

A. Isolated grounding systems may only be installed with the permission of the electrical standards point of contact.

B. In addition to the equipment-grounding conductor, install a dedicated 600-volt insulated isolated grounding conductor with each isolated ground branch circuit.[67] *The purpose of isolated grounding systems is to reduce common-mode noise in circuits serving sensitive electronic equipment.*

1. Use green insulation with a yellow stripe.
2. Make the isolated ground conductors the same size as the circuit phase conductors.
3. Connect the isolated ground conductors to the isolated ground bars in panelboards and to the isolated ground terminals at receptacles and equipment.

C. Refer to LANL Master Specification Section 26 0526, *Grounding and Bonding for Electrical Systems,* for additional guidance.

7.3 Signal Reference Grid (Requirement 7-0065)

A. Signal Reference Grids may only be installed with the permission of the electrical standards point of contact.

B. Install a signal reference grid (SRG) for computer room raised floor areas.[68] Refer to IEEE Std. 1100, *Powering and Grounding Electronic Equipment* for additional design guidance.

C. Use one or a combination of the following systems:[69]

1. Pre-fabricated grid of flat copper strips on 2 feet centers with all crossover connections factory welded. Bond every sixth raised floor pedestal to the SRG using 6 AWG grounding conductor.
2. Raised floor pedestal system with bolted down metal horizontal stringers.
3. 2 ft. x 2 ft. grid of bare 6 AWG conductors clamped to raised floor pedestals.

D. Bond structural steel columns, pipes, conduits, and ducts, etc. passing through the SRG to the SRG using No. 6 AWG grounding conductor.

E. Bond computer equipment, power panels, and computer distribution units to the SRG using low impedance risers (LIRs).

1. Install LIRs made of 2 inch wide, 26-gauge copper strips or 1-inch-wide flexible braided copper straps.

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67 Recommended practice for isolated ground systems in Chapter 8 of IEEE 1100.
68 Recommended practice for equipment within a contiguous area in Chapter 8 of IEEE 1100.
69 Recommended practice for signal reference grids in Chapter 8 of IEEE 1100.

2. Do not connect any LIR to the SRG conductor at the outside edge of the SRG.
3. Keep the LIRs as short as possible.
4. If a LIR exceeds 24 inches, install two parallel LIRs connected to opposite corners of the equipment. Make the second LIR 20 percent to 40 percent longer than the first.

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

7.4 Control of Static Electricity (Requirement 7-0066)

A. Control static electricity to prevent fire and explosion.[70] This requirement applies to all locations where there is the potential to create an ignitable mixture and electrostatic energy can be created, accumulated, and discharged with energy exceeding the minimum ignition energy of the mixture; such locations include:

- Bottle racks
- Flammable storage cabinets
- Drum storage/dispensing racks
- Loading docks and other transfer points
- Processing equipment
- Storage tanks.

B. Use methods and materials described in NFPA 77, *Recommended Practice on Static Electricity.*

C. Refer to LANL Master Specification Section 26 0526, *Grounding and Bonding for Electrical Systems,* for additional guidance.

8.0 INTERIOR LIGHTING

8.1 Design (Requirement 7-0067)

A. Design interior lighting systems in accordance with the following standards and guides:

1. IES RP-1, *Office Lighting* (ANSI).
2. IES RP-7, *Industrial Facilities* (ANSI).
3. IES *Lighting Handbook, Tenth Edition*.
4. ASHRAE/IES Standard 90.1, *Energy Standard for Buildings except Low-Rise Residential Buildings*.

B. To ensure quality of the visual environment and efficient illumination, coordinate interior finishes with the architect or interior designer to determine surface reflectances. Preliminary values are recommended in the IES *Lighting Handbook* as follows:

1. Office environments (e.g., offices, conference rooms, laboratories):[71]

[70] Refer to NFPA 77.
[71] Refer to Chapters 22 and 3032 in the IES Lighting Handbook.

- Ceilings: 90%
- Walls: 60%
- Floors: 20%

2. Industrial environments (e.g., shops, process spaces, warehouses):[72]
   - Ceilings: 90%
   - Walls: 60%
   - Floors: 20%

C. Integrate lighting systems with daylighting systems to increase occupant satisfaction and conserve energy. Consider daylighting effects in any space where daylight is admitted, even if it is not exploited as a light source, to avoid glare and damage to materials.[73]

D. Perform lighting calculations using procedures[74] outlined in the IES *Lighting Handbook*. Lighting calculations for each interior space shall include the following:

1. IES illuminance category selection (horizontal and vertical), uniformity target, and the underlying logic for selection.[75]
2. Design illuminance and logic for any departure from the recommenced values in the IES Lighting Handbook.
3. Light loss factors and the underlying logic for their selection.
4. Calculated average initial and maintained illuminance based on the installed system. Calculated average "maintained" illuminance for the installed system shall be between –10 and +10 percent of the IES recommended illuminance.

E. Satisfy the uniformity criteria and other criteria important to a high-quality visual environment as presented in the IES Lighting Handbook.[75]

F. Design interior illumination for gloveboxes based on the specific visual tasks to be performed in each glovebox.[76] *Proven existing glovebox illumination designs may be used to the extent that the visual tasks in the new gloveboxes will be similar to those that have been performed successfully in the existing gloveboxes.*

1. Satisfy the criteria for a high-quality visual environment presented in the IES Lighting Handbook for the industrial visual tasks that best approximate the specific visual tasks to be performed in each glovebox.

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72 Refer to Chapters 22 and 30 in the IES Lighting Handbook.
73 Refer to Chapter 14 in the IES Lighting Handbook.
74 Refer to Chapter 10 in the IES Lighting Handbook.
75 Refer to the relevant chapter in the applications section of the IES Lighting Handbook, 10th Edition.
76 Lesson learned from the CMRR RLUOB project.

2. Select luminaire type and location based on the specific visual tasks to be performed in each glovebox in accordance with Chapter 30 in the IES *Lighting Handbook*.[77]

3. Meet illumination criteria in AGS-G001 *Guideline for Gloveboxes* and ASTM C852 *Design Criteria for Plutonium Gloveboxes*:

   - Design to provide illuminance of approximately 100 foot-candles at the work surface and 50 foot-candles general illumination.
   - Provide means to adjust illuminance both inside and outside the glovebox to minimize glare.
   - Use luminaires with louvers, baffles, or other means to diffuse light and shield the lamps from direct view by the glovebox user.
   - Consistent with decontamination requirements, provide flat, matte, non-glossy finishes on the interior surfaces of gloveboxes to reduce glare.

G. Perform calculations[78] to show that the installed interior lighting power does not exceed the ASHRAE/IES Standard 90.1 "interior lighting power allowance."[79]

1. Contracted design organization shall certify that the lighting system complies with the requirements of ASHRAE/IES Standard 90.1.[80]

2. Certification shall bear the seal and signature of the professional engineer in responsible charge of the lighting system design.[81]

8.2 Luminaires and Lamps

A. Coordinate selection of luminaires with user's functional needs, visual tasks to be performed, the type of equipment that will be used (e.g., computer terminals), architectural finish materials, and the environment in which the luminaires will be operating. In all applications, LED lighting should be the first choice. (Requirement 7-0068)

B. For other-than-LED luminaire installations, select luminaires to facilitate cost-effective maintenance of lamps, ballasts, and luminaire parts such as reflectors and lenses. Use long-life lamps, remote ballasts, lowering devices, etc. as required by the installation location.[82] (Requirement 7-0069)

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77 Visual tasks in glove boxes are often difficult and diverse and require a specific quantity and quality of lighting that cannot be obtained by general lighting methods. Before supplemental task lighting can be specified, the designer must understand the nature of the visual task as well as its light-reflecting or transmitting characteristics.

78 Refer to Section 4 ASHRAE/IES Standard 90.1.

79 Refer to Section 9 in ASHRAE/IES Standard 90.1.

80 Certification by the design agency will be accepted instead of a detailed review of the compliance documents required in Section 4 in ASHRAE/IES Standard 90.1.

81 Required by New Mexico Engineering and Surveying Practice Act (Chapter 61, Article 23 NMSA 1978).

82 Refer to Chapter 19 in the IES Lighting Handbook.

C. For other-than-LED luminaire installations, minimize the number of lamp and ballast types on each project.[83] (Requirement 7-0069)

D. Use lamps that pass the EPA *Toxicity Characteristic Leachate Procedure* (TCLP)[84] test for hazardous waste determination or LED sources that are RoHS[85] certified.

E. For accent and display lighting, down-lighting, and special purpose lighting in interior spaces, use LED luminaires.[86]

F. In interior spaces subject to radiological contamination, use LED luminaires[87] for general lighting, task lighting, and special-purpose lighting except where a very high radiation dose (e.g., a Co-60 gamma ray dose greater than 150 Mrad[88]) would reduce LED output to less than 70 percent of the initial output in less than 80 percent of the rated life. *Luminaires specifically designed for LED light sources are preferable to conventional luminaires that are retrofitted with LED light sources.* (Requirement 7-0069)

G. For LED lighting in interior spaces, use 120V[89] luminaires with the performance characteristics listed below (Requirement 7-0070):

1. Minimum luminaire efficacy per IES LM-79, *Approved Method: Electrical and Photometric Measurement of Solid-State Lighting Products*:
   - 90 lumens/watt for general lighting
   - 50 lumens/watt for accent and display lighting, down-lighting, and special purpose lighting.
2. Correlated color temperature (CCT) per IES LM-79 and ANSI/NEMA/ANSLG C78.377, *Specification for the Chromaticity of Solid-State Lighting (SSL) Products*:
   - 3500 ºK for general lighting and down-lighting
   - 2700 ºK for accent and display lighting, and special purpose lighting.

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83 Minimizing the number of lamp and ballast types reduces the costs and inventory required to maintain a building lighting system.

84 The Toxicity Characteristic Leaching Procedure (TCLP) is designed to simulate the leaching a waste will undergo if disposed in a sanitary landfill. Refer to EPA SW-846, "Test Methods for Evaluating Solid Waste (Physical/Chemical Methods)," Chapter 7, "Toxicity Characteristic Leaching Procedure," page SEVEN-13.

85 Restriction of Hazardous Substances Directive (or RoHS) restricts the use of six hazardous materials (lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls, and polybrominated diphenyl ethers) in the manufacture of various types of electronic and electrical equipment, including LEDs and associated drivers.

86 Incandescent light sources for accent lighting are rapidly being removed from the market through legislative and administrative actions. Compact fluorescent sources are not really suitable for accent lighting due to the large light emitting area that makes spotlighting difficult.

87 LED sources contain no mercury or lead; this coupled with the lower replacement rate will result in lower disposal cost. This is a very significant factor in radiological areas due to hazardous/mixed waste disposal issues. Ordinarily, fluorescent and HID lamps are classified as "Universal Waste" and are disposed in accordance with 40CFR273; however, in a radiological area, these same lamps may be classified as "Hazardous/Mixed Waste" and must then be disposed in accordance with 40CFR261.3 and RCRA 42 U.S.C.A. 6903(41). Disposal cost for "Hazardous/Mixed Waste" is much higher than for "Universal Waste." Refer to LANL P409, *Waste Disposal*.

88 Refer to Applied Physics Letters 87, 212107 (2005) "High Dose Co-60 Gamma Irradiation of InGaN Quantum Well Light-Emitting Diodes," Khanna, Han, Pearton, D. Schoenfeld, W, V. Schoenfeld, and Ren.

89 277-volt luminaires may be used with the permission of the electrical standards point of contact. 277-volt systems are more expensive to work on because of maintenance requirements and restrictions.

3. Color rendering index (CRI): 80 or better.[90]
4. LED Design life (L70): Not less than 50,000 hours per IES LM-80, *Approved Method: Measuring Lumen Maintenance of LED Light Sources*.
5. Driver System Design Life: Not less than the LED design life; note that the driver system includes all associated components, not just the driver integrated circuit. Driver system design life is defined as when 2 percent of the systems would have failed.
6. Power factor: 0.90 or better.
7. Design ambient temperature: 35 °C (95 °F); note that this is the ambient temperature surrounding the luminaire, not the LED or driver heat-sink temperature.
8. Nominal operating altitude: 7500 ft.
9. EMI/RFI: Meet FCC 47 CFR Part 15.
10. Audible noise: Class A sound rating.
11. Minimum dimming provisions or capability:
    - 50% step for general lighting
    - Down to 20% for accent and display lighting, and special purpose lighting.

H. For fluorescent general lighting in interior spaces, use 120V luminaires with energy-saving electronic ballasts, and energy-efficient lamps.

1. For T-8 or T-5 fluorescent lamps use electronic energy-saving ballasts. Use "programmed start" electronic ballasts for fluorescent lamps when occupancy sensors control the system.
2. For lensed luminaires, parabolic louver luminaires, and low-bay direct applications use T-8 fluorescent lamps with the following salient features:
    - 3500 ºK color temperature.
    - Color rendering index (CRI) of 75 or better.
3. For indirect lighting, direct/indirect lighting, direct lighting for high-bay applications, and wall-washing applications use either the T-8 lamps or high-output T-5 fluorescent lamps. with the following salient features:
    - 3500 ºK color temperature.
    - Color rendering index (CRI) of 80 or better.
4. For re-lamping of existing luminaires containing 48-inch T-12 fluorescent lamps, use T-12 lamps with the following salient features:
    - Spot re-lamping: Color temperature to match existing lamps and color rendering index (CRI) of 70 or better.

[90] A CRI in the 90s is not desirable because of the uneven spectrum of light (high in the Reds, low in the Blues). A good color spectrum is more important than the CRI number.

- Group re-lamping: Color temperature and CRI as specified for T-8 lamps.

I. For re-lamping of existing incandescent luminaires for accent and special purpose lighting in interior spaces use LED A-lamp replacements or Energy Star, energy saving, screw-base, compact fluorescent lamps with the following salient features:

1. 2700 or 3000 ºK color temperature.
2. Color rendering index (CRI) of 80 or better.

Note: For explosion-proof luminaires, verify with manufacturer that re-lamping with compact fluorescent lamps or LED A-lamp replacements will maintain the characteristics and NRTL listing of the luminaire and the lamp.

J. Select lamp/ballast and LED/driver combinations that will start and operate properly in the ambient environment. (Requirement 7-0054)

K. Select luminaires for general illumination of office environments (e.g., private offices, open plan offices, conference rooms, and laboratories) using the following criteria and the criteria in Chapters 12, 22, and 32 of the IES *Lighting Handbook*:

1. Where the ceiling height is less than 9'-0" use lay-in or recessed troffers with initial candlepower not exceeding the values in Table 12.4 of the IES *Lighting Handbook*.
2. When the ceiling height in office or laboratory environments is 9'-0" or higher, use indirect or direct/indirect distribution, pendant or cable suspended luminaires unless they will interfere with equipment to be installed in the space. Suspend luminaires not less than 18 inches below the ceiling and the bottom of the luminaires not less than 7'-6" above the finished floor. Design the lighting system to provide a maximum ceiling luminance not exceeding values indicated in Table 12.4 of the IES *Lighting Handbook*.

L. Select luminaires for general illumination of industrial environments using the following criteria and the criteria in Chapters 22 and 30 of the IES *Lighting Handbook*:

1. Where luminaires will be mounted more than 25 ft. above the floor use "high bay" fluorescent, pulse-start metal-halide, or LED luminaires:
   - Use "high bay" fluorescent luminaires[91] that have a 10% to 30% upward component and T5 high-output fluorescent lamps with a minimum color rendering index (CRI) of 80 and a color temperature of 4100 ºK.

[91] Fluorescent industrial luminaires are "instant-on" facilitating use with occupancy-sensing lighting controls and eliminating the need for supplemental lighting as is required for HID sources that require extended time to start or re-start after a brief power interruption.

- Use enclosed[92] "high bay" pulse-start metal-halide[93] luminaires that shield the light source not less than 25 degrees from the horizontal and have a 10% to 30% upward component. Use lamps with a minimum color rendering index (CRI) of 65 and a color temperature of approximately 4000 ºK. Use supplemental instant-on lighting to provide a minimum of 1 fc illuminance while HID lamps start or re-start.[94]

2. Where luminaires will be mounted 15 to 25 ftt. above the floor use "low bay" fluorescent, pulse-start metal-halide, or LED luminaires:
   - Use "low bay" fluorescent luminaires that have louvers to control glare, 5% to 20% upward component, and T5 high output fluorescent lamps with a minimum color rendering index (CRI) of 80 and a color temperature of 4100 ºK.
   - Use enclosed "low bay" pulse-start metal-halide luminaires that have prismatic lens to control glare. Use lamps with a minimum color rendering index (CRI) of 65 and a color temperature of approximately 4000 ºK. Provide supplemental instant-on lighting providing a minimum of 1 footcandle illuminance while HID lamps are starting or re-starting.
3. Where luminaires will be mounted 15 ft or less above the floor use LED or fluorescent industrial luminaires that shield the light source not less than 25 degrees from the horizontal perpendicular to the fixture and have a 10% to 30% upward component. Use lamps with a minimum color rendering index (CRI) of 75 and a color temperature of approximately 3500 ºK.

M. Space luminaires at approximately 0.65 times the maximum spacing to mounting height ratio to reduce the effects of a single lamp failure.[95]

N. In machine shops and similar environments, circuit luminaires to minimize stroboscopic effects from HID, LED, and fluorescent light sources. Operate luminaires on alternate phases of the 3-phase power supply.[96]

O. Refer to LANL Master Specifications Section 26 5100, *Interior Lighting,* for additional guidance.

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92 Metal-halide lamps may suffer catastrophic end of life failure; lamp manufacturer's catalog data recommends enclosed luminaires.

93 Pulse-start metal-halide technology provides significant operating and maintenance cost improvements over conventional probe-start metal halide lighting systems. Pulse-start metal halide lighting provides "white light" that is much more accepted by occupants than high-pressure sodium's "golden-white" light, with only slightly higher life cycle cost.

94 Illuminance level for safety is from Chapter 25 in the IES Lighting Handbook. Pulse-start metal-halide lamps require 2 to 3 minutes to warm-up when initially started and 4 to 6 minutes to re-strike after a momentary power interruption.

95 Refer to 5.2.3.1 in IES RP-7-01.

96 Refer to 3.7 in IES RP-7-01.

8.3 Lighting Control (General Lighting) (Requirement 7-0071)

A. For all new buildings and renovations in existing buildings, design lighting controls that comply with the requirements in ASHRAE/IES Standard 90.1.[97] Note: If the renovation only includes new lighting (the existing controller is not being replaced), this requirement does not apply.

B. In existing buildings, for all lighting control device replacements, design controls that comply with the requirements in ASHRAE/IES Standard 90.1.[98]

C. *Sustainable Design Guidance: For new construction & modernization (NC&M), when subject to the Guiding Principles for Sustainable Federal Buildings (per ESM Ch. 14), and pursuing GP certification, consider GP 4, Enhancing the Indoor Environment, specifically GP 4.2, Daylighting and Lighting Controls. GP 4.2 is as follows:*

Maximize opportunities for and benefits of daylighting in regularly occupied space to introduce daylight and views into the spaces, except where not appropriate because of building function, mission, or structural constraints; reinforce circadian rhythms; and reduce the use of electrical lighting. Ensure appropriate lighting controls and task lighting.

D. *When pursuing LEED certification, consider the following:*

1. *The Integrative Process Credit for lighting level considerations during pre-design.*
2. *Indoor Environmental Quality Credit*
3. *Daylight, Sustainable Sites Credit*
4. *Light Pollution Reduction, and Indoor Environmental Quality Credit*

E. Design occupancy sensing switching for all spaces with ceiling high partitions including the following spaces:[99]

- Private offices
- Laboratories
- Computer rooms
- File rooms
- Storage rooms
- Lobbies
- Open offices
- Conference rooms
- Break rooms
- Copy machine rooms
- Restrooms
- Corridors

Exceptions to the above requirement are spaces where lighting is intended for 24-hour operation and spaces where an automatic shutoff would endanger the safety or security of the room or building occupant(s). For example, automatic control of lighting is not allowed in electrical rooms, per NFPA 70.

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97 Requirements in Section 9 of ASHRAE/IES Standard 90.1 are extended to all LANL buildings, including those smaller than 5000 sq. ft. Occupancy sensor controls make it economical to provide automatic lighting shut-off in the smallest buildings.

98 Requirement in Section 4 of ASHRAE/IES Standard 90.1.

99 Occupancy sensor controls are adopted as the method for achieving the automatic lighting shutoff required in Section 9 of ASHRAE/IES Standard 90.1.

F. Adjust time-out settings for occupancy sensors to optimize energy saving, relamping cost, and customer satisfaction. The following optimal settings have been determined: [100]

1. Classrooms, private offices, open offices, laboratories, and restrooms: longest time-out setting, but not more than 30 minutes.
2. Break rooms, storage rooms, copy machine rooms: 5-minute time-out setting
3. Conference rooms: 10-minute time-out setting
4. Corridors, lobbies: 15-minute time-out setting
5. Any area that uses Fluorescent instead of LED: 30 minutes to 1 hour[101]

G. Design combined ambient light and occupancy sensing switching or combined ambient light and time clock switching for spaces or zones that receive daylighting from exterior windows or skylights.[102] Use ambient light sensors hold off or reduce the electric lighting contribution when daylighting exceeds 80% of the design illuminance at the work area. Make measurements at desk height in the center of the room. *In a typical office with a design illuminance of 50 footcandles, the ambient light sensor should hold the lights off as long as the daylighting exceeds 40 footcandles.*

H. Dual-Level Control

1. Use dual-level light switching or dimmer control in areas 100 square feet and larger.[103]
2. Coordinate manual controls with automatic controls so that the manual control can reduce connected lighting load by at least 50 percent in a reasonably uniform illumination pattern.[104] *In a typical room with three-lamp fluorescent luminaires, arrange circuiting so the occupancy sensor controls all three lamps and the wall switch, connected on the load side of the occupancy sensor, controls two lamps.*
3. Arrange luminaires and level-control circuiting to correspond to daylight apertures. *In a typical side lighting design with windows along one wall, it is best to place the luminaires in rows parallel to the window wall and circuit so the row nearest the window will be the first to dim or switch off followed by successive rows.*

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[100] Optimum occupancy sensor time-out settings based on technical paper "The Effects of Changing Occupancy Sensor Time-out Setting on Energy Savings, Lamp Cycling, and Maintenance Costs," Journal of the Illuminating Engineering Society, Vol. 30, No. 2, pp 97-110.

[101] Switching on and off fluorescent lamps significantly decreases their life, due to the stress caused by the striking voltage necessary to turn the lamps on.

[102] Integrating daylighting controls into the building lighting control will reduce electrical and cooling loads.

[103] Dual-level switching allows users to reduce energy consumption when performing less demanding visual tasks.

[104] Dual-level control allows users to set illuminance to match task requirements, thus conserving energy. Drawn from California Title 24.

I. In corridors design un-switched "night lighting" luminaires at the entrance/exit to the corridor and at major corridor intersections. *Night lighting luminaires may also be part of the emergency lighting system described below.*

J. In spaces with more than one personnel entrance, design the lighting controls so any required manual control will be available at each entrance.[105]

K. Refer to LANL Master Specification Section 26 2726, *Wiring Devices,* for additional guidance.

8.4 Installation (Requirement 7-0072)

A. Coordinate luminaire layout with building structure, architectural ceiling grid, furniture and equipment layout, HVAC ducts and diffusers, piping, and sprinkler heads.

B. Connect each luminaire in suspended ceilings using a wiring method that will facilitate relocation of the luminaire to adjacent grid openings. Suitable wiring methods include:

1. 6-ft fixture whips.
2. Manufactured wiring system as described in the NEC.[106]

C. Install luminaires using materials and methods that will facilitate maintenance.

D. Install interior lighting systems in accordance with the manufacturer's instructions, and the following standards:

NECA/IES 500, *Recommended Practice for Installing Indoor Commercial Lighting Systems*.

NECA/IES 502, *Recommended Practice for Installing Industrial Lighting Systems*.

E. Refer to LANL Master Specification Section 26 5100, *Interior Lighting*, for additional guidance.

9.0 EXIT AND EMERGENCY LIGHTING

9.1 General (Requirement 7-0073)

A. Design emergency lighting and marking of means of egress in accordance with the *National Electrical Code*,[107] the *International Building Code*,[108] and NFPA 101 *Life Safety Code*.[109]

[105] Refer to Chapter 16 in the IES Lighting Handbook.
[106] Refer to NEC Article 604.
[107] Refer to NEC Article 700.
[108] Refer to Sections 1006 and 1011 in the International Building Code.
[109] Refer to Chapter 7 in NFPA 101, *Life Safety Code*.

B. Perform lighting calculations using appropriate procedures[110] as outlined in the IES *Lighting Handbook*.

C. Emergency lighting, whether unit equipment or a luminaire with an emergency lighting package, shall be provided with an external test button to facilitate monthly testing.

D. Egress lighting must remain illuminated at all times when the room or space that the egress path is serving is occupied. (Requirement 7-0083)

E. Control by Fire Alarm Panel (New Construction[111]): If the egress lighting is on a control system that shuts the lighting off during unoccupied periods, the egress lighting controls must be connected to the building's fire alarm panel such that the egress paths will be illuminated upon activation of the fire alarm system. Also, per "D" above, the egress paths must also be illuminated if the motion control sensors in the areas served detect occupant movement. (Requirement 7-0084)

9.2 Emergency Lighting Unit Equipment (Requirement 7-0074)

A. Use emergency lighting unit equipment that is UL 924 listed and labeled for the intended use.

1. In finished spaces of office and laboratory LANL facilities with fluorescent or LED luminaires use emergency battery/inverter units with the self-test feature described below.[112]

2. For typical service and industrial spaces in LANL facilities use wall-mounted, receptacle-connected incandescent or LED unit equipment with the self-test feature described below.[113] Install a dedicated receptacle adjacent to each emergency lighting unit.

3. Certain locations in special facilities may have environments or other conditions that require special emergency lighting unit equipment suitable for the application.[114] Review such applications with the Electrical Chapter POC.

B. Where commercially available, use emergency lighting units that automatically perform a self-test of battery and lamps for not less than 30 seconds every 30

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110 Note that zonal cavity methods or point-by-point illuminance calculations are typically not valid when making calculations for emergency lighting systems. Emergency luminaires are often too widely spaced, and resulting illumination is too non-uniform for these methods to be acceptable. Refer to Chapters 10 and 25 in the IES Lighting Handbook for specific calculation methods.

111 The connection of the lighting system controls to the fire alarm system is only practical in new installations where a new fire alarm panel and a new lighting control system being installed.

112 Inverter ballast units improve the aesthetics of finished spaces compared to cord-connected wall-mounted incandescent unit equipment. Some authorities say that the diffuse illumination provided by ceiling fluorescent luminaires is more conducive to orderly evacuation.

113 Emergency lighting equipment is standardized and cord-connected to facilitate maintenance.

114 Examples of special applications include corrosive environments, contamination environments, or spaces (such as bio-safety labs) that must have a minimum of surfaces to clean. Architectural preference alone is inadequate reason to use other than standard wall-mounted unit emergency lighting equipment.

days and have a visual status indicator to indicate any failure.[115] *Some special spaces, such as laser laboratories, may require that only manual testing be performed.*

C. Connect emergency lighting unit equipment to the branch circuit serving normal lighting in the area and ahead of any local switches. In lighting panelboards, clearly identify the branch circuits that serve unit emergency lighting equipment.[116]

D. Refer to LANL Master Specifications Section 26 5200, *Safety Lighting,* for additional guidance.

9.3 LED Emergency Exit Signs (Requirement 7-0075)

A. Where practical, use LED emergency exit signs that are UL924 listed and labeled for the intended use and meet EPA "Energy Star" standards.

B. Specify exit signs with green[117] LED lamps producing a minimum luminance of 8.6 cd/m^2.[118]

C. New and replacement emergency exit signs shall automatically perform a self-test of battery and lamps for not less than 30 seconds every 30 days[119]; a visual status indicator shall indicate any failure. Units shall also perform tests that are manually initiated by a test button.

D. Connect emergency exit signs to the branch circuit supplying normal lighting in the area and ahead of any local switches. In the lighting panelboards, clearly identify the branch circuits that supply emergency exit signs.[120]

E. Refer to LANL Master Specifications Section 26 5200, *Safety Lighting*, for further guidance

9.4 Non-Powered Exit Signs (Requirement 7-0076)

A. Do not use self-luminescent (tritium) exit signs for any purpose except in structures that require exit signs but do not have electrical power.[121]

B. Use photoluminescent exit signs only in special circumstances such as the following:

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115 Periodic testing of emergency lighting equipment is required in section 7.9.3 of NFPA 101-2000, *Life Safety Code*. Automatic self-testing is permitted; this feature greatly reduces the time required to test and maintain the emergency lighting system. Monthly visual inspections are still required.

116 Required by section 700.12(F) in the NEC; re-stated for emphasis.

117 Green is the color that has been used for exit signs at LANL for many years; some authorities say that green exit signs are more visible than red.

118 Refer to Chapter 25 in the IES Lighting Handbook.

119 NFPA 101, paragraph 7.10.9.2 establishes testing requirements for internally illuminated exit signs.

120 Required by Article 700 in the NEC.

121 Self-luminous exit signs contain radioactive tritium. Increasingly stringent accountability requirements and uncertainty of future disposal costs weigh against continued use of these devices at LANL. Using current procurement, operating, maintenance, and disposal costs, the 20-year life cycle cost of a LED emergency exit sign is about the same as that for a self-luminous exit sign. The 20-year life cycle cost of a photoluminescent exit sign is less than for a self-luminous exit sign.

1. Hazardous areas as defined in the NEC.
2. When existing self-luminous (tritium) exit signs fail or reach the end of their rated life.[122]

C. Evaluate the use of photoluminescent exit signs on a case-by-case basis and use only in locations meeting the following criteria: [123]

1. The face(s) of the sign will be continuously illuminated to not less than 5 foot-candles from a fluorescent or metal-halide source while the structure is occupied.
2. Illumination will be from a reliable source that is not controlled by automatic timers or occupancy sensors.
3. Manual controls and switches will be accessible only to authorized persons.
4. The ambient temperature will be between 50°F and 104°F.

D. Where photoluminescent exit signs cannot be used, evaluate the cost-effectiveness of using LED emergency signs. (as determined by the FOD)

E. Where the use of photoluminescent exit signs is not possible and the use of LED powered emergency exit signs is not cost effective, existing Tritium self-luminous exit signs will be replaced in kind from a supplier that will provide for the disposal of the existing Tritium exit sign.

F. Refer to LANL Master Specifications Section 26 5200, *Safety Lighting*, for additional guidance.

10.0 EXTERIOR BUILDING LIGHTING

10.1 Selection (Requirement 7-0077)

A. Design building-mounted safety and security lighting for exterior doors, stairways, loading docks, mechanical equipment yards, and parking lots and pedestrian walkways located adjacent to the building.[124]

B. Perform lighting calculations using procedures outlined in the IES *Lighting Handbook*. Use point-by-point methods for exterior applications.[125]

C. Select exterior lighting systems following guidance in the IES *Lighting Handbook*.[126]

D. Minimize the number of luminaire types.

E. Use high-efficiency, low maintenance luminaires (*e.g., LED*) with cut-off type distribution that complies with the State of New Mexico "Night Sky Protection

122 ESM variance request on self-luminous exit sign replacements approved on 3/31/04.
123 Refer to UL 924 supplement SG.
124 Refer to Chapter 26 in the IES Lighting Handbook.
125 Refer to Chapter 10 in the IES Lighting Handbook.
126 Refer to Chapter 26 in the IES Lighting Handbook.

Act"[127]. *The International Dark-Sky Association "Lighting Code Handbook" provides useful guidance.*

F. Select, locate, and aim luminaires to minimize unintentional illumination of adjacent terrain and so that glares are not directed towards any guard station or roadway.[128]

G. Refer to LANL Master Specification Section 26 5100, *Interior Lighting,* and 26 5600, *Exterior Lighting*, for further guidance

10.2 Control

A. Design exterior building lighting controls that comply with the requirements in ASHRAE/IES Standard 90.1. [129] (Requirement 7-0078)

B. Control exterior lighting to be on at dusk and off at dawn by means of photocells through HAND-OFF-AUTO selector switch and lighting contactor. (Requirement 7-0079)

C. Refer to LANL Master Specification Section 26 5600, *Exterior Lighting,* for additional guidance.

10.3 Installation (Requirement 7-0080)

Install exterior lighting systems in accordance with the manufacturer's instructions, the NEC, and NECA/IES 501, *Recommended Practice for Installing Exterior Lighting Systems*.

RECORD OF REVISIONS

Rev	Date	Description	POC	OIC
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, *PM-2*	Dennis McLain, *FWO-FE*
1	11/18/02	General revision and addition of endnotes. Replaces Subsections 211.3, 211.4, 214, 215, 216, 217, 244, 245.4, 245.5, 245.6, 245.7, 248, 251, 252, and 253.	David W. Powell, *FWO-SEM*	Kurt A. Beckman, *FWO-SEM*
2	05/18/05	Updated references to LANL Construction Specifications; updated references to NEC; clarified requirements for remote control wiring; added requirements for receptacles in copy rooms; modified requirements for isolated-ground receptacles; revised requirements for adjustable-frequency drives; clarified motor selection criteria; incorporated variance for replacement of self-luminous exit signs.	David W. Powell, *ENG-DECS*	Gurinder S. Grewal, *ENG-CE*

[127] The "Night Sky Protection Act" was passed by the 44th New Mexico State Legislature, 1st Session of 1999, Chapter 197, House Bill 39. Its purpose is to regulate outdoor lighting to preserve and enhance the state's dark sky while promoting safety, conserving energy, and preserving the environment for astronomy.

[128] Refer to Chapter 26 in the IES Lighting Handbook. LEDs are very directional and, therefore, minimize the risk of unwanted light or glare

[129] Refer to Section 9 in ASHRAE/IES Standard 90.1.

3	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, *FM&E-DES*	Kirk Christensen, *CENG*
4	11/3/08	Updated codes and standards. Added criteria for raceways and cords under raised floors. Prohibited multi-wire branch circuiting. Added lab receptacle circuiting criteria. Reduced unit load for office PC outlets that share networked printers. No receptacles within 3 feet of gas meters or regulators. Added criteria for electric drinking fountain circuits. Clarified selection of heavy-duty receptacles. Added welder outlet requirements. Skid-mounted equipment to be accordance with NFPA 79. Control panels must be NRTL-listed. Added criteria for safety switches where short-circuit current exceeds 10 kA. Added requirements for use of Drawing ST-D5020-1. Permitted use of T-5 fluorescent lamps for certain applications. Required use of compact fluorescent lamps when re-lamping incandescent luminaires. Added criteria for glovebox illumination. Added requirement for manual lighting control at each personnel entrance to a room. Added more definitive criteria for emergency lighting calculations. Photoluminescent exit signs to be used in place of self-luminous (tritium) exit signs.	David W. Powell, *ES-DE*	Kirk Christensen, *CENG*
5	11/8/11	Changed GFCI accessibility and location requirements. Added requirements for residential portions of facilities. Revised AFC location and redundancy requirements for AFCs with graded approach. Corrections in Table 5020-4. Augmented illuminance criteria for glovebox interiors. Updated IES Lighting Handbook references to the Tenth Edition. Major changes for LEDs. Clarified characteristics of fluorescent lamps for re-lamping.	David W. Powell, *ES-DE*	Larry Goen, *CENG-OFF*
6	10/13/22	Added Purpose/Scope. Numerous other changes throughout. Incorporated VAR-2014-046, Non-Powered Exit Signs; VAR-10183, Allowance for multi-wire branch circuits; VAR-10139, Dedicated Equipment-grounding Conductors and Raceways, and VAR-10548, Elimination of Restrictions on Flexible Cords and Cables. Removed requirement to perform life cycle cost analysis for LED luminaires. Removed requirements for special computer receptacles and combined into general-purpose receptacles. Added requirement to use European voltage transformers to supply European equipment. Adjusted requirements for the size of motor that can be started on a transformer. Removed locations of where GFCIs are required when the requirement is already in NFPA 70. **Added Requirements ID Log references (LANL internal-use log posted with chapter)**	Eric Stromberg, *ES-EPD*	Michael Richardson, *ES-DO*