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D5020 LIGHTING & BRANCH CIRCUIT WIRING

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1.0 RACEWAY AND BOXES

1.1 Raceways

A. Use raceway systems to contain premises wiring systems.[1] *Metal-clad (MC) cable may be used for 15 and 20 ampere branch circuit wiring in IBC Group B Occupancies beyond the first outlet or junction box; refer to paragraph 2.4 in this Section.*

B. Size raceways considering all conductor adjustment factors required by the NEC.

C. Indicate sizes of branch circuit conduits and wireway sections on the design drawings and any changes on the record as-built drawings.[2]

D. In addition to locations required by the NEC, require conduit sealing fittings with approved sealant at the following locations:

1. Where conduits cross the boundary of a radiological area.[3]
2. Where conduits pass between areas where air pressure differential must be maintained.[4]
3. Where conduits enter an enclosure protected by a clean agent total flooding fire suppression system.[5]

E. Design raceways penetrating radiation shielding or permanent contamination zones with sufficient bends, curvature, or shielding to prevent radiation streaming through the void.[6]

F. Use materials and installation methods described in LANL Master Specification Section 26 0533, *Raceways and Boxes for Electrical Systems*.

G. Use surface metal raceway where there is a high density of receptacle outlets such as at laboratory benches and in computer server rooms. Use surface metal raceway with internal divider(s) to contain power and telecommunications distribution.

1. Use surface metal raceway in accordance with the NRTL listing for the product.
2. Use base, covers, and fittings designed by the manufacturer to be assembled together.
3. Only NRTL-listed, fixed multi-outlet assemblies may have the branch circuit loads calculated based on NEC, Section 220.14(H).[7]

H. 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[8] determined in

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1 LANL institutional policy developed through observation and experience. Installation of wiring systems in raceway systems protects conductors and facilitates future wiring modifications. This also aligns with the New Mexico Electrical Code which prohibits non-metallic sheathed cable wiring methods in commercial and industrial occupancies.

2 Accurate design and as-built documentation facilitates maintenance and future system modifications.

3 The purpose of sealing raceways crossing radiological areas is to prevent the spread of contamination.

4 Occupancies such as bio-safety labs use air pressure differentials to assure containment.

5 Refer to NFPA 2001, *Standard on Clean Agent Fire Extinguishing Systems*. To prevent loss of [fire suppression] agent through openings to adjacent areas, openings shall be permanently sealed.

6 DOE 6430.1A, Section 1300-6.2, Shielding Design, states that straight-line penetration of shield walls shall be avoided to prevent radiation streaming.

7 Lesson learned on LANL project. AE had calculated load for receptacles in surface metal raceway as if it were multi-outlet assembly. NEC requirement repeated for emphasis.

8 Full-scale fire testing of exposed cables in cable trays shows that listed/approved CMP cabling exhibits better fire resistance, limited flame spread, lower heat release rates and reduced smoke and toxic products of combustion development

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*.

1.2 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.[9]

B. Use materials and installation methods described in LANL Master Specification Section 26 0533, *Raceways and Boxes for Electrical Systems*.

1.3 Boxes

A. Design complete system of outlet boxes, junction boxes, and pull boxes that meet requirements of the NEC and are compatible with all other related systems.

B. Coordinate locations of outlet boxes with furniture and equipment.

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

D. Use materials and installation methods described in LANL Master Specification Section 26 0533, *Raceways and Boxes for Electrical Systems*.

2.0 CONDUCTORS AND CABLES

2.1 Wiring Color Codes

A. Identify all branch circuit conductors (phase, grounded, and grounding conductors) using color-coding that is consistent throughout the building.[10] *For minor work*[11] *in existing facilities use wiring color codes that match existing color codes so long as National Electrical Code requirements for identifying grounded and grounding conductors are met*[12].

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

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characteristics than other cable materials approved for installation in computer room under floor spaces - thereby reducing loss potentials associated with direct fire and smoke damage to sensitive data processing equipment, reduced equipment downtime and lower adverse impact on computing operations and mission commitments. Cable, raceways, boxes and fittings having fire resistant properties approximating those of CMP cabling align with the highly protected risk (HPR) philosophy indicated by DOE O 420.1B Chapter II paragraph 3.a.1 to minimize fire risk within NNSA computing facilities.

[9] Purpose of flexible connection is to reduce noise transmission and allow equipment movement. 18 inches is about the minimum length effective for equipment adjustment or vibration isolation.

[10] Color coding of phase conductors facilitates wiring system voltage identification and the correct installation of equipment requiring a specific phase sequence or phase rotation.

[11] Refer to ESM Chapter 7, D5000, "Application of this Chapter" heading.

[12] Refer to NEC Sections 200.6 and 250.119.

2.2 Building Wire and Cable

A. Use copper conductors that have been sized with consideration to adjustment factors for voltage drop, ambient temperature, raceway fill, harmonics, and future loading.[13]

B. Indicate the number and size of conductors in conduit runs, wireway sections, and cable tray sections on the design drawings and any changes on the record as-built drawings.[2]

C. Use copper conductors for branch circuit wiring. Aluminum is not acceptable.[14]

D. Use minimum No. 12 AWG for branch circuit wiring.[15]

E. Design branch circuit conductors for 3 percent maximum voltage drop at full-design load.[16] Use voltage drop calculation methods outlined in Chapter 3 of IEEE Std 141.

F. Do not use “multi-wire” branch circuits. Require a dedicated grounded (neutral) conductor for each branch circuit that requires a neutral.[17]

G. 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.[18]

H. Use materials and installation methods described in LANL Master Specifications Section 26 0519, *Low Voltage Electrical Power Conductors and Cables*.

2.3 Remote Control Wiring

A. Comply with NEC Article 725.

1. Install life safety, safety-class, safety-significant, and other critical remote control wiring in conduit systems.
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.*

B. Class 1, line voltage (120V), and safety-related remote control wiring:

1. Use stranded copper conductors with 600V THHN/THWN insulation.
2. Terminate wiring using crimp-on ring tongue or pin-type lugs as appropriate for the terminal.[19]

C. Class 2 and Class 3 remote control wiring:

1. Use stranded multi-conductor cable; use twisted-pair shielded cable for circuits carrying analog signals or digital data.
2. Install Class 2 and Class 3 remote control wiring in separate raceways from line voltage and Class 1 remote control wiring.
3. Terminate Class 2 and Class 3 remote control conductors directly in terminal blocks.

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13 Adjustments for raceway fill, ambient temperature, and harmonics are required in NEC Article 310.15.
14 The New Mexico Electrical Code prohibits the use of aluminum conductors smaller than No. 2; this prohibition is extended to all branch circuit conductor sizes at LANL.
15 The use of minimum 12 AWG on branch circuits limits voltage drop.
16 AHSRAE/IES Standard 90.1 requires the stated voltage drop design criteria.
17 IEEE Std 1100, *IEEE Recommended Practice for Powering and Grounding Electronic Equipment* (Emerald Book); Chapter 8 recommends a dedicated grounded conductor (neutral) for each branch circuit.
18 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*.
19 Crimp-on lugs increase the reliability of terminations for stranded control conductors.

4. Ground cable shields at the controller end; insulate cable shield at the field device end.

D. Install remote control wiring without splice or tap from wiring terminal to wiring terminal.

E. Label remote control wiring using wire markers at both ends with complete "from" and "to" terminal information. Identify the panel, terminal block, and terminal number. Use materials and installation methods described in LANL Master Specifications Section 26 0553, *Identification for Electrical Systems*.

2.4 Metal-Clad Cable

A. *In IBC Group B Occupancies, metal-clad cable (Type MC) may be used for branch circuit wiring systems.*[20, 21, 22]

B. For branch circuits serving multiple outlets use conduit from the first outlet or junction box to the branch circuit panelboard.[23]

C. Use of Type MC is limited to interior, dry locations in Group B occupancies where it will be concealed above suspended ceilings, in dry-wall partitions, in equipment enclosures, or below raised floors.[24] Type MC may be installed exposed in dedicated electrical rooms and mechanical rooms if not be exposed to physical damage or deteriorating agents.

D. Use 12 AWG minimum conductor size.

1. Use larger size as required by the NEC.
2. Use larger conductor sizes as required to limit voltage drop as required in this Section.
3. Use larger conductor sizes to adjust allowable ampacity if there are more than 3 current-carrying conductors in a cable. Refer to NEC Article 310.15 for adjustment factors.[25]

E. For isolated ground power circuits use cable with a separate grounded conductor for each phase conductor. Uniquely color-code each grounded conductor to associate it to the corresponding phase conductor.

F. Use materials and installation methods described in LANL Master Specifications Section 26 0519, *Low Voltage Electrical Power Conductors and Cables*.

2.5 Flexible Cord and Cable

A. Use flexible cords, cables, and their associated fittings that are UL approved and suitable for the conditions of use.[26] Consider temperature, operating voltage, and exposure to moisture, oils, chemicals, sunlight, ozone, and physical abrasion in selecting cords and cables.

B. Use flexible cords and cable only for the following applications:[27]

[20] IBC group B includes offices, computer rooms, and light laboratories. For these types of occupancies, Type MC may be a more cost-effective wiring method than conventional wire in conduit.

[21] A cost analysis using office space meeting the lighting and receptacle requirements of this Chapter shows that the metal clad cable wiring method saves about $1.65 per square foot compared to wire in EMT. Costs used are from the 2000 Means Electrical Cost Data Book; these costs are conservative because LANL costs are 2 or 3 times national averages.

[22] IEEE Std 1100, in Chapter 8, discusses the advantages of metal-clad cable for branch circuits serving electronic equipment.

[23] Use of conduit for the branch circuit homeruns will facilitate the future addition of branch circuits from the panelboard to the vicinity of new loads.

[24] NEC Article 330 permits MC cable to be installed exposed; however LANL institutional policy is to conceal this wiring method in finished spaces.

[25] NEC Article 310.15 ampacity adjustments apply to conductors in MC cable.

[26] Refer to ESM Chapter 7, D5000, "NRTL Listing" heading, which requires the use of listed materials in accordance with their intended use.

[27] Uses permitted are based on NEC Section 400.7.

1. Pendant receptacles for 15, 20, or 30 amp 120, 120/240, or 208Y/120V circuits.
2. Exposed connections for lighting fixtures.
3. Connections of portable lamps and appliances using an attachment plug and energized from a receptacle outlet.
4. Connections of stationary equipment to facilitate their frequent interchange using an attachment plug and energized from a receptacle outlet that is mounted on the structure.
5. Connection of appliances where the fastening means and mechanical connections are specifically designed to permit ready removal for maintenance or repair and the appliance is intended or identified for flexible cord connection using an attachment plug and energized from a receptacle outlet.
6. Connection of moving parts.
7. For temporary wiring as permitted by the NEC during construction, remodeling, repairs, emergencies, tests, experiments, and developmental work. Remove temporary wiring immediately upon completion of the construction, remodeling, repair, emergencies, tests, experiments, or developmental work for which it was installed.

C. Use flexible cords and cables containing a green insulated equipment-grounding conductor to provide an effective ground-fault current path.[28]

D. Use flexible cords and cables only in continuous lengths without splices or taps.[29]

E. Flexible cords and 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 except where the cord or cable is supplied as part of an NRTL listed appliance.[30]

F. Flexible power cords used under raised floors (e.g. computer rooms, server rooms) must be Type DP in accordance with UL 1690 – *Standard for Data Processing Cables*.

3.0 WIRING DEVICES

3.1 Receptacle Outlets

A. Design receptacle outlets at locations required and in sufficient density to minimize or eliminate the use of extension cords, re-locatable power taps, and outlet strips.[31]

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

C. Provide 120-volt, 15- or 20-ampere[32] general-purpose duplex receptacle outlets connected to 20-ampere[33] 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[34] unless noted otherwise.

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28 An effective ground-fault current path is required in NEC Article 250 to limit the voltage to ground on electrical equipment.

29 Requirement for no splices or taps in portable cords is expanded from NEC Article 400.9 to improve personnel safety and reduce fire hazards.

30 Portable power cords and cables are expected to be subjected to hard usage in harsh environments.

31 Reduction of the use of extension cords, power strips, and relocatable power tabs will reduce fire and electrocution hazards and will improve power quality.

32 The NEC permits multiple 15-ampere receptacles to be served by a 20-ampere circuit. This provides adequate service and permits the use less costly 15-ampere wiring devices.

33 The use of 20-ampere general-purpose branch circuits is standard commercial and industrial design practice.

34 180 VA per receptacle strap is the minimum load for receptacle outlets permitted by NEC Article 220. Use of this load permits the use of the receptacle load demand factors in NEC Section 220.13.

1. Hard wall enclosed offices, conference rooms, copy rooms, laboratories, and similar spaces: One outlet on each wall plus additional outlets so no point measured horizontally in any wall space is more than 6 ft from a general-purpose receptacle outlet.[35]
2. Open-office workstations: At least two outlets plus additional 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 outlet.
3. Laboratory countertops: At least one outlet for each 3 ft of countertop.[36]
4. Kitchens and break rooms: At least one outlet on each wall where not used for counters.
5. Equipment rooms: At least one outlet plus additional receptacle outlets so all equipment that may require maintenance is within 25 ft of a receptacle.[37] *See requirement below for GFCI receptacles in mechanical equipment rooms.*
6. Corridors: 20-ampere receptacle outlets on dedicated circuit(s) for custodial use located so no point on any corridor floor is more than 25 ft from an outlet.[38]
7. Copy rooms: One outlet on each wall plus additional outlets so no point measured horizontally in any wall space is more than 6 ft from a general-purpose receptacle outlet. At least one outlet for each 3 ft of countertop or fraction thereof for small office equipment such as FAX machines and printers. At least one 20 ampere receptacle on an individual circuit for a copy machine. *Some copy rooms may have high-capacity printers requiring higher-capacity circuits*.

D. Provide 120-volt, 15 or 20-ampere, double-duplex[39] PC receptacle outlets connected to dedicated circuits[40] at the locations described below and at locations dictated by the User's functional and operational requirements to serve PCs, monitors, and printers:

- Hard wall enclosed offices: At least two outlets located on opposite walls.[41]
- Open-office workstations or cubicles: At least one outlet.
- Laboratories: At least one outlet.
- Conference rooms: At least one outlet located at the front of the room. At least one floor outlet located centered under the conference table for audio-visual and teleconferencing equipment.
- Mechanical rooms: At least one outlet in each mechanical room for building automation system equipment.

1. Unless the User has more definitive requirements, use the unit loads in Figure D5020-2 for double-duplex receptacle outlets in office and laboratory occupancies.

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35 Receptacle spacing is based on the 6-ft cords supplied with most electrical equipment used in offices. Adequate accessible receptacle outlets will reduce or eliminate the need for extension cords and portable outlet strips.
36 3-ft spacing of receptacles at lab workbenches provides a reasonable capacity for general bench-top laboratory equipment.
37 At least one receptacle outlet is required so cords do not pass through doorways. Locating receptacles within 25 ft of equipment requiring maintenance will keep extension cord use within reasonable limits.
38 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.
39 A double-duplex receptacle outlet provides a plug connection for the computer, monitor, speaker amplifier, and printer that comprise a typical PC station.
40 IEEE Std 1100 in Chapter 8 recommends that office work stations have separate, dedicated branch circuiting and receptacles for electronic equipment and another separate receptacle circuit for convenience loads or high impact loads such as electric heaters, hand tools, and copy machines.
41 Many LANL offices have more than one computer station.

Figure D5020-2 PC Workstation Loads[42]

PC Workstation Equipment	Average Measured Current (Amps)	Unit Load (Volt-Amps)	Feeder/Service Demand Factor
Computer	3.00	360	100%
Monitor	1.72	206	100%
Printer	3.75	450	100%
Load per double-duplex receptacle		1016	100%

2. *For outlets serving secure office PC stations operating in the "KVM" mode the branch circuit load per double-duplex receptacle may be reduced to 566 VA.*
3. *For outlets serving office PC stations that share networked printers and do not include "personal printers" the branch circuit load per double-duplex receptacle may be reduced to 566 VA.*
4. For computer or instrument circuit receptacles not connected to SPD protected circuits, use UL 1449 (Standard for Safety for Transient Voltage Surge Suppressors) listed, 125 volt, 15- or 20-ampere, surge suppression type duplex receptacles.[43]

E. Provide 120-volt, 15 or 20-ampere duplex ground-fault circuit-interrupter (GFCI) type receptacle outlets[44] 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 receptacle outlets so they will be accessible for monthly testing[45] 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 serve them from GFCI circuit breakers; label the receptacle outlets "GFCI Protected."

1. Outdoor locations, including roofs: At least one outlet within 25 ft of mechanical equipment that may require maintenance.[46, 47] Locate outlets at least 3 ft from gas meters and pressure regulators.[48]
2. Outdoor locations: At least one outlet within 6 feet of each personnel and vehicle entrance plus additional outlets so no point measured horizontally on the building perimeter is more than 80 ft from a receptacle outlet. [49]
3. Laboratory and experiment areas: Any outlets located within 6 feet of the outside edge of a sink. (At least one receptacle outlet in each laboratory must be non-GFCI.[50])
4. Laboratory, experiment, battery, and chemical areas: Any outlets located within 6 feet of an emergency shower/eyewash station.
5. Kitchen/break areas: At least two outlets serving the countertop area(s).[51] Provide at least one outlet for each countertop space that is 12 inches or wider.[52] Provide receptacle and

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42 Based on survey and measurement of 89 computer workstations in PM Division during the summer of 1999.
43 Section D5010 establishes 30 outlets as the point for providing a panel-mounted TVSS; for less than 30 outlets, TVS-type receptacles are a more economical alternative.
44 Ground fault receptacles are usually more economical and more reliable than ground fault circuit breakers, especially on long branch circuits. Users can re-set GFCI receptacles, but only qualified electrical workers wearing proper PPE are permitted to re-set GFCI circuit breakers in panelboards.
45 NEC Section 210.8 requires that ground- fault circuit-interrupters be readily accessible.
46 Uniform Mechanical Code, 2000 Edition, paragraph 309.0 requires a receptacle outlet within 25 ft of mechanical equipment.
47 NEC section 210.8(B) requires GFCI protected receptacle outlets.
48 Refer to Chapter 5 in NFPA 54 *National Fuel Gas Code*.
49 80-ft receptacle spacing allows a 100-ft cord to reach all points within 60 ft of the building exterior.
50 Non-GFCI receptacle is for critical equipment such as laboratory refrigerators that must not unintentionally be shut off.
51 NEC Section 210.8(B) requires GFCI receptacles in non-dwelling kitchens.
52 NEC Section 210.52(C) is extended to non-dwelling occupancies.

dedicated 20-amp circuit for each vending machine. Design distribution system using a unit load of 1500 VA per circuit.[53]

6. Bathroom, locker room, and shower areas: At least one above-counter outlet within 36 inches of each lavatory bowl. At least one below lavatory counter to serve power supplies for proximity-sensing electronic faucets and flush valves.
7. Mechanical equipment rooms: At least one outlet plus additional outlets so all equipment that may require maintenance is within 25 ft of a receptacle. [46]
8. Janitor closets. At least one outlet.[54]
9. Receptacle outlets for vending machines. For each vending machine, provide an outlet connected to a dedicated 20-amp circuit; for load calculations use a unit load of 1500 VA per circuit.
10. Indoor wet locations.
11. Garages, service bays, and similar areas where electrical diagnostic equipment, power tools, or portable lighting will be used.
12. Static-grounded areas: Provide outlets to meet the User's functional and operational requirements.[55]
13. Electric drinking fountains: Provide outlet(s) connected to dedicated 15-amp circuit(s); for load calculations use a unit load of 480 VA per electric drinking fountain.[56]

F. Provide 120-volt, 15 or 20-ampere isolated ground type receptacle outlets served by isolated-ground circuits for equipment that is sensitive to common-mode noise including:

1. Equipment in an information technology equipment room as defined in NEC Article 645 and NFPA 75.
2. Equipment in telecommunications server equipment rooms and RED server equipment rooms as described in ESM Chapter 7 Section D5030.
3. Other locations as dictated by the User's functional and operational requirements.

G. 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 "guest rooms, guest suites, dormitories, and similar occupancies."

H. Coordinate receptacle locations with furniture and equipment layout so receptacle outlets will be accessible.

1. In common areas (conference rooms, break rooms, etc.) install receptacle (and telecommunications) outlets with center 18 inches above the finished floor.[57] Locate outlets to comply with Americans with Disabilities Act Accessibility Guidelines (ADAAG), 28 CFR Part 36, Appendix A.
2. Locate wall mounted receptacle (and telecommunications) outlets in hard wall-enclosed offices with center 7" above the finished floor (immediately above the cove base).[58, 59]

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[53] Unit load for receptacle outlets in kitchen and break areas is to adequately serve User-supplied vending machines, coffee makers and microwave ovens.

[54] Outlet is to serve battery chargers for battery-powered janitorial equipment.

[55] The DOE Explosives Safety Manual, paragraph 7.8, recommends GFCI receptacles in static grounded areas.

[56] GFCI protection of electric drinking fountains is required by NEC section 422.52. Unit load is from typical EWC vendor's catalog data.

[57] 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.

[58] Office spaces with special ADAAG accommodations will be provided on an as-needed basis.

[59] The 7" center mounting height will allow the outlet device plate to be completely above a 4" cove base and below furniture "modesty panels" that are typically 9-1/4" AFF.

Coordinate locations of receptacle outlets with modular furniture and associated hangers to assure that receptacles will be accessible.[60]

3. Coordinate mounting height of receptacle outlets at lab benches and counters with architectural details. The maximum height to meet ADAAG requirements is 44 inches.[57]

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

J. Select and design heavy-duty receptacle outlets as follows:

1. If an NRTL-listed appliance or equipment item is supplied with an attached cord and plug that is suitable for the application and location, specify a receptacle to match the plug.
2. If the appliance or equipment item is not supplied with a suitable plug, specify a 20, 30, 60, or 100-ampere pin and sleeve type receptacle and matching plug that are listed to UL 1682, *UL Standard for Safety Plugs, Receptacles, and Cable Connectors of the Pin and Sleeve Type*, and conform to UL 1686, *UL Standard for Safety Pin and Sleeve Configurations*, configuration C2 (IEC Standard 60309).
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 with the receptacle energized.[61]

K. Provide receptacle outlets for electric welders in mechanical equipment rooms where maintenance or future modification of piping or equipment may require welding. Consider receptacle outlets for electric welders in process equipment rooms, laboratories, and similar spaces where maintenance or future modification of piping or equipment may require welding.[62]

1. Density: At least one outlet per 1800 sq ft or fraction thereof; provide and locate outlets 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.
4. Circuit rating: In accordance with NEC Article 630, based on the rating plate data for individual welder rating plate data and the duty cycle for an individual welder or a group of welders on the circuit.
5. Circuit source: Panelboard or switchboard that does not serve noise-sensitive loads.

L. Connect receptacle outlets to branch circuits as follows:

1. Connect a maximum of eight general-purpose duplex receptacles per 20-amp circuit.[63]
2. Connect a maximum of two double duplex PC receptacles per 20-amp circuit.[64] Install a dedicated grounded conductor for each circuit (no multi-wire branch circuits). Install a dedicated equipment-grounding conductor for each circuit. Install branch circuits to PC receptacles in separate raceways from general-purpose receptacles.[65]
3. Connect laboratory glovebox, fume hood, and bench top receptacles as follows:

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60 Lesson learned form LANL construction projects.
61 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.
62 Lesson learned from CMRR RLUOB project.
63 Limit of eight general-purpose receptacles per circuit aligns with the New Mexico Electrical Code.
64 Two double duplex receptacle outlets would be capable of serving two PC stations with a total branch circuit load of 2032 VA or 16.93 amps. This loading of a 20-amp circuit is permissible because the PC station load is not continuous.
65 Recommended practice from Chapter 8 in IEEE Std 1100.

- Where loads that will be connected to receptacles are known, design branch circuiting based on the loads; connect up to 8 receptacles per 20-amp circuit.
- Where loads to be connected to receptacles are not known, connect a maximum of four receptacles per 20-amp circuit.[66]

M. Test each 15- and 20-ampere, 120-volt receptacle using a UL listed tester that impresses a momentary load of at least 15 amperes on the branch circuit conductors and the equipment-grounding path.[67]

N. Use materials and installation methods described in LANL Master Specifications Section 26 2726 - *Wiring Devices*.

3.2 Receptacle Plates

A. For flush mounted receptacles use brushed 302/304 alloy stainless steel plates.[68]

B. For surface mounted receptacles use galvanized steel, 4-inch square covers.

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.[69]

D. Use materials and installation methods described in LANL Master Specifications Section 26 2726 - *Wiring Devices*.

4.0 WIRING CONNECTIONS

4.1 General

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

B. Use materials and methods described in Sections D5000, D5010, and D5020 of this chapter and suitable for the installation location and environment.

C. Install receptacle outlets, 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.

E. Some specialized, non-domestic, and possibly non-NRTL-listed laboratory equipment will require power with different characteristics (voltage, frequency, etc.) than that available in the facility. Design and specify the power conversion or transformation apparatus required for safe and proper operation of the equipment. Non-NRTL-listed laboratory equipment, special power conversion apparatus (frequency converters, buck-boost transformers, etc.), and their installation must be approved by the LANL electrical AHJ.[70]

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

67 The common neon lamp receptacle testers can give false indications of proper grounding. Testers that impose a load on the ground path are more likely to identify faulty grounds or incorrect receptacle connections.

68 Stainless steel plates provide greater durability than other materials.

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

70 Refer to Chapter 5 in LANL P101-13, *Electrical Safety Program*.

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.[2]

4.2 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*.[71]

5.0 MOTORS AND MOTOR CONTROLLERS

5.1 Motor Controllers

A. Provide an NRTL listed, 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[72] 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. Apply motor controller types as follows to limit voltage dips to acceptable levels: [73]

1. Full-voltage starting may be used for motors with locked rotor kVA not exceeding 25 percent of the utility supply transformer(s) base (self-cooled) kVA rating.
2. Use reduced voltage starting (electro-mechanical, solid-state “soft start”, or variable speed drive) for motors with locked rotor kVA exceeding 25 percent of the utility supply transformer(s) base (self-cooled) kVA rating.
3. If a motor will be served by a standby or emergency power system, use reduced voltage starting (electro-mechanical, solid-state, or variable speed drive) if the locked rotor kVA exceeds 10 percent 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.[74]

C. Use a control voltage of 120V or less.[75] Refer to “Remote Control Wiring” in Section D5020 for additional requirements.

D. Provide LED type indicator lights on the front of each magnetic controller.[76] 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:[77]

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71 Refer to NEC Article 670 and NFPA 79.
72 Refer to paragraph 5.1.5 in LANL P101-13 *Electrical Safety Program*.
73 Criteria for motor starting from Chapter 3 of IEEE Std 141.
74 Required by NEC Section 110.9.
75 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.
76 LED pilot lights are more reliable and require less maintenance than incandescent pilot lights.
77 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 (Stop/Danger/Hazard) denotes a system or component that is energized, running, or closed.
2. GREEN (Go/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.
   - 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 assure operation of the equipment in the required sequence.
   - 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 assure that automatic controls will not re-start the motor.*

H. For three phase motor starters serving motors with full load current up to and including 300 amperes, provide solid state motor starter overloads as described in LANL Master Specifications Section 26 2913, *Enclosed Controllers*.

I. For motor starters serving 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.[78]

K. Position packaged equipment to obtain the NEC required clearances to integral control equipment.[79]

L. Use material and installation methods described in LANL Master Specifications Section 26 2913, *Enclosed Controllers*.

5.2 Motor Control Centers

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 served.

B. Provide motor control centers with short circuit rating that exceeds the available fault current.

C. Provide motor control centers with main bus capable of 20% future load growth. Provide 10% spare starters (not less than one) and 10% spare spaces (not less than one) in each motor control center for future use.[80]

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

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

D. Refer to LANL Master Specifications Section 26 2419, *Motor Control Centers* for material and installation requirements.

5.3 Adjustable Frequency AC Controllers

A. In addition to the requirements for magnetic combination type starters, use the following requirements and guidance for selecting adjustable frequency AC controllers (AFCs) serving induction motors for fans and centrifugal pumps:

1. Use configured AFCs 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 AFCs with the building automation system using ANSI/ASHRAE Standard 135, ISO 16484-5 approved BACnet-compatible communications.

3. Interface AFCs 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

4. De-rate AFC capacity 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.*

B. Provide AFCs with redundancy as described below: [81] *NOTE: Some safety significant and all safety class systems will have fully-redundant trains, making VFD redundancy not necessary.*

1. 3-contactor isolation and bypass system for VFDs serving 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 AFCs with manual transfer switch for AFCs serving 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 AFCs. *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 AFCs that might be purchased as spares.*

C. Locate AFCs at locations that are:

1. Accessible by authorized persons and provide the NEC-required working clearances.

2. Supplied with sufficient ventilation/cooling to dissipate the heat from the AFC while maintain suitable ambient conditions for the AFC.

3. Suitable to accept or adequately attenuate the audible noise generated by the AFC.

D. Locate PWM-type AFCs as close as practical to the motors they serve. If the distance from the AFC to the motor must exceed 100 ft provide RFI/EMC filters or other means to limit high frequency voltage in the motor windings.

[80] The combination of spare starters and spaces is intended to fulfill the requirement for future 20% growth.
[81] Refer to *Consulting Specifying Engineer*, March 2010 article "Dual VFDs Versus Bypasses: Engineers Weigh In" for a detailed discussion of dual AFCs, bypasses, and spare AFCs.

E. Avoid installing a safety disconnect switch between AFCs and motors. If a safety disconnect must be installed, interlock the controller run-permissive circuit using an auxiliary switch in the disconnect.

F. In addition to the harmonic mitigating features specified for individual AFCs, 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 519-1992, *IEEE Recommended Practices and Requirements for Harmonic Control in Electric Power Systems.*

1. If the total connected kVA of AFCs exceeds 15 percent of the self-cooled kVA rating of the facility service 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.
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 AFCs are operating at 80% speed.

G. Refer to LANL Specification Section 26 2923 *Adjustable Frequency Motor Controllers* for material and installation requirements.

5.4 Manual Starters

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.

5.5 Motor Disconnecting Means

A. Install disconnecting means within sight of each motor and its driven equipment.[82] *The motor controller disconnecting means can serve as the motor disconnecting means if it is within sight of the motor and its driven equipment.*

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

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.

[82] Refer to NEC Section 430.102(B). Since few LANL facilities are "industrial installations," condition (b) in the Exception to Section 430.102(B) can't be used for most LANL facilities. The definition of "Supervised Industrial Installation" in NEC Section 240.2 is also applicable to motor installations.

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

C. For single-phase motors use NRTL-listed, horsepower-rated toggle switches.

D. Provide the appropriate NEMA enclosure type for the environment.

E. Provide permanently installed padlocking provision for each motor disconnecting means.[83]

F. Locate disconnecting means at either the controller or the motor to be readily accessible.[84]

G. Refer to LANL Master Specification Section 26 2816 *Safety Switches and Enclosed Circuit Breakers* for material and installation requirements.

5.6 Motor Connections

Use NRTL-listed motor lead splicing kits for insulating and sealing bolted pigtail and in-line 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.[85]

5.7 Motors

A. Use NEMA Premium labeled[86] energy efficient motors for new installations and for replacements of motors that have failed. 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.

B. Select motor rated voltage to economically serve the load, to match building system voltage(s), and to limit voltage dip when starting the motor.[87] *Use the following as guidance in selecting motor rated voltages:*

1. *200V, 230V, or 460V, 3-phase, 60 Hz for motors 1 HP and larger; match building secondary service voltage.*
2. *460V, 3-phase for motors 25 HP and larger.*
3. *4160V, 3-phase for motors 500 HP and larger.*
4. *120V, single phase, 60 Hertz for motors smaller than 1 HP.*

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

84 Requirement in NEC section 430.107 repeated for emphasis.

85 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.

86 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.

87 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. with a service factor greater than 1.0).[88]

D. De-rate motors for operation at 7500 ft. altitude 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.

[88] 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.

Table 5020-4 Motor Selection Table[89]

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.

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[89] 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 adjustable frequency AC controllers 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.

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

5.8 Motor Control Diagrams

A. Use ESM Standard Drawing ST-D5020-1 as a template for project motor control diagrams.[90]

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.

6.0 GROUNDING

6.1 Enclosure and Equipment Grounding

A. Provide a 600-volt, insulated (green) equipment ground conductor in each branch circuit raceway and in each raceway for line voltage control wiring and non-power-limited wiring systems.[91] Size equipment-grounding conductors as required in the NEC.

B. An equipment grounding conductor 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.[92]

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

6.2 Isolated Grounding System

A. In addition to the equipment-grounding conductor, install a dedicated 600-volt insulated isolated grounding conductor with each isolated ground branch circuit.[93] *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 circuit the 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.

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

[90] Refer to ESM Chapter 7 Section D5000 paragraph 4.3-L.
[91] 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.
[92] Refer to NEC Section 300.10.
[93] Recommended practice for isolated ground systems in Chapter 8 of IEEE 1100.

6.3 Signal Reference Grid

A. Install a signal reference grid (SRG) for computer room raised floor areas.[94] Refer to IEEE Std. 1100, *Powering and Grounding Electronic Equipment* for additional design guidance.

B. Use one or a combination of the following systems:[95]

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.

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

D. 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.
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.

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

6.4 Control of Static Electricity

A. Control static electricity to prevent fire and explosion.[96] 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* and in LANL Master Specification Section 26 0526, *Grounding and Bonding for Electrical Systems*.

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94 Recommended practice for equipment within a contiguous area in Chapter 8 of IEEE 1100.
95 Recommended practice for signal reference grids in Chapter 8 of IEEE 1100.
96 Refer to NFPA 77.

7.0 INTERIOR LIGHTING

7.1 Design

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

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 assure quality of the visual environment and efficient illumination, coordinate interior finishes with the architect or interior designer to obtain the initial surface reflectance recommended in the IES *Lighting Handbook*:

1. Office environments (offices, conference rooms, laboratories, etc.):[97]
   - Ceilings: 90%
   - Walls: 60%
   - Floors: 20%
2. Industrial environments (Shops, process spaces, warehouses, etc.):[98]
   - 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, in order to avoid glare and damage to materials.[99]

D. Perform lighting calculations using procedures[100] 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.[101]
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.[101]

F. Design interior illumination for gloveboxes based on the specific visual tasks to be performed in each glovebox.[102] *Proven existing glovebox illumination designs may be used to the extent*

97 Refer to Chapters 22 and 32 in the IES Lighting Handbook.
98 Refer to Chapters 22 and 30 in the IES Lighting Handbook.
99 Refer to Chapter 14 in the IES Lighting Handbook.
100 Refer to Chapter 10 in the IES Lighting Handbook.
101 Refer to the relevant chapter in the applications section of the IES Lighting Handbook, 10th Edition.
102 Lesson learned from the CMRR RLUOB project.

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.
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*.[103]
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 footcandles at the work surface and 50 footcandles 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[104] to show that the installed interior lighting power does not exceed the ASHRAE/IES Standard 90.1 “interior lighting power allowance.”[105]

1. Contracted design organization shall certify that the lighting system complies with the requirements of ASHRAE/IES Standard 90.1.[106]
2. Certification shall bear the seal and signature of the professional engineer in responsible charge of the lighting system design.[107]

7.2 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, etc.), architectural finish materials, and the environment in which the luminaires will be operating.

B. 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.[108]

C. Minimize the number of lamp and ballast types on each project.[109]

D. Use lamps that pass the EPA *Toxicity Characteristic Leachate Procedure* (TCLP)[110] test for hazardous waste determination or LED sources that are RoHS[111] certified.

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[103] 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.

[104] Refer to Section 4 ASHRAE/IES Standard 90.1.

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

[106] 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.

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

[108] Refer to Chapter 19 in the IES Lighting Handbook.

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

E. For accent and display lighting, down-lighting, and special purpose lighting in interior spaces use LED luminaires.[112]

F. In interior spaces subject to radiological contamination, use LED luminaires[113] 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[114]) 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.*

G. For projects pursuing LEED certification, use LED lighting systems unless life-cycle cost analysis shows that LED systems will have higher life-cycle cost than other LANL standards-compliant lighting systems (then they are optional).[115] *Other factors may supersede or modify cost considerations.*

1. For life-cycle cost comparison between LED luminaire lighting systems and other LANL standards-compliant lighting systems use the National Institute of Standards and Technology (NIST) Building Life-Cycle Cost (BLCC) Program in conjunction with NIST Handbook 135, *Life Cycle Costing Manual for the Federal Energy Management Program*, Chapter 18 of the IES *Lighting Handbook, and ESM Chapter 1 Section Z10 Attachment E.*
2. Use the sum of not less than ten representative spaces from the Project for the life-cycle cost comparison. *Examples of representative spaces include staff offices, open offices, laboratories, corridors, and conference rooms.*
3. Include differences in HVAC system equipment costs and associated HVAC energy and maintenance costs in the life-cycle cost comparison.
4. To assure a fair life-cycle cost comparison, use the IES Zonal Cavity lighting calculation method and the factors in Table 5020-5 to determine quantities and types of luminaires and resulting power requirements.

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110 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.

111 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.

112 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.

113 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*.

114 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.

115 LED lighting systems may not be life-cycle cost-effective for general lighting when compared to fluorescent lighting systems in 2011, but ESM Chapter 14 establishes circumstances where the efficiency gains of LEDs would warrant their higher initial cost (e.g., LEED and 10CFR433 drivers). It is expected that LED lighting systems will become cost-effective within the next 5 years (i.e., by 2016).

Table 5020-5 Lighting Calculation Factors

	Fluorescent luminaires with T-8 lamps and program start ballasts	Fluorescent luminaires with T-5HO lamps and program start ballasts	LED luminaires
Lamp initial lumens	2800	5000	Based on the particular LED luminaire
Ballast factor (BF)	0.88	1.00	1.00
Lamp lumen depreciation at mean life (LLD)	0.95	0.94	0.875
Luminaire dirt depreciation (LDD)	0.98	0.98	0.98
Lamp burnout factor (LBF)	0.95	0.95	1.0
Rated lamp life (hr)	20,000	20,000	50,000
Lamp replacement	Group re-lamping at 70% of rated life	Group re-lamping at 70% of rated life	Luminaires[116] or LEDs replaced at 80% of rated life
Power input to luminaire	60 watts for two F32T8 lamps	117 watts for two F54T5HO lamps	Based on the particular LED luminaire

5. Consider the following factors in the LED lighting system decision:
   (a) First cost:
      - *In 2011, the first cost of an LED lighting system is higher than a comparable fluorescent or HID lighting system; however, during the next decade this cost difference will decrease due to advances in the core technologies, product development, and improvements manufacturing processes that will increase yield and uniformity.*
      - *The July 2010 DOE sponsored Solid-State Lighting Research and Development: Manufacturing Roadmap projects solid-state LED luminaire costs to be $50/kilo-lumen in 2010, $10/kilo-lumen by 2015, and $5/kilo-lumen by 2020.*

   (b) Energy efficiency:
      - *LEDs produce more lumens per watt (efficacy) than fluorescent lamps.*
      - *Conventional fluorescent lamps generally have emission in all directions, which can result in lower luminaire efficiencies due to the light that is absorbed in the luminaire. Light emitted from an LED device is more directional and controlled, so less light is lost within the luminaire.*

[116] In 2011, few LED luminaires for general lighting include provisions for user-replacement of individual LEDs, so at end-of-life the entire luminaire must be replaced. This may change as this product market matures and evolves.

- *In an air conditioned space the cooling load for an LED lighting system will be less than for an equivalent fluorescent lighting system.*
- *Improvement in LED efficacy will continue with advances in materials and electronics technology.*

(c) Operating life. *The operating life of LED sources (>50,000 hours) is longer than fluorescent or HID lamps. This will result in lower maintenance costs – significantly lower costs in radiological areas, security areas, or difficult to access locations. Researchers indicate that LED operating life will continue to improve as the technology develops.*

(d) Durability:

- *Inherent in the LED solid-state light production mechanism is the ability to resist vibration and impact, The LED is encased in a tough epoxy plastic resin instead of a fragile glass bulb, so the device is resistant to shattering or impact damage.*
- *LED sources (but not necessarily the associated driver electronics) can be used in high radiation environments. For example, InGaN LEDs irradiated by a Co-60 gamma ray source have only a 20 percent loss of light output after accumulating a dose of 150 Mrad.*

(e) *S*afety/Security Improvements:

- *LED luminaires typically use multiple LEDs that are unlikely to fail simultaneously, leading to increased reliability for safety or security lighting applications.*
- *Unlike HID luminaires, standard LED luminaires are instant full-on with no re-start time after a momentary power interruption.*
- *The lower maintenance rate for LED luminaires will mean fewer entries by maintenance personnel into contaminated or secure areas and less work from ladders or lifts to maintain lighting systems.*

(f) Disposal costs: *Fluorescent and HID lamps contain mercury, a toxic substance that may require special handling for disposal; in contrast, LEDs contain no mercury and require no special handling for disposal. This coupled with the lower replacement rate will result in lower hazardous waste disposal costs. This can be a significant factor in radiological areas due to hazardous/mixed waste issues.*

(g) Performance at Low Temperatures: *LED performance inherently improves as ambient operating temperatures drop.*

(h) Smaller Package Size: *Due to their compact size, LED devices are an excellent option where size or weight is a concern. Their small size gives LEDs increased design flexibility for use in special applications. It is reasonable to expect that novel luminaires will be developed with system architectures and form factors taking advantage of the unique properties of LEDs.*

(i) Dimmability and controllability: *LED luminaires can be designed with dimming controls and motion sensors to adjust brightness levels and even adapt to changes in room characteristics. LED A-type replacements have recently become commercially available, and unlike compact fluorescent alternatives, offer dimming capabilities similar to that of conventional incandescent lamps.*

(j) Color Rendering: *LED luminaires are available with a color rendering index (CRI) over 90. This compares to a CRI of 78 for 3500K T-8 32 watt fluorescent lamps. CRI is important where a critical color-matching task is performed.*

H. For LED lighting in interior spaces, use NRTL-listed 120V or 277V luminaires with the performance characteristics listed below:

1. Minimum luminaire efficacy per IES LM-79-08, *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-79-08 and ANSI/NEMA/ANSLG C78.377-2008, *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.
3. Color rendering index (CRI): 90 or better per IES LM-79-08.
4. LED Design life (L70): Not less than 50,000 hours per IES LM-80-08, *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.

I. For fluorescent general lighting in interior spaces, use 120V or 277V luminaires with energy-saving electronic ballasts, and energy-efficient lamps.

1. For T-8 or T-5 fluorescent lamps use NRTL-listed 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.
   - Group re-lamping: Color temperature and CRI as specified for T-8 lamps.

J. 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.

K. Select lamp/ballast and LED/driver combinations that will start and operate properly in the ambient environment.

L. 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*.

M. 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 or pulse-start metal-halide luminaires:
   - Use “high bay” fluorescent luminaires[117] that have a 10% to 30% upward component and T5 high-output fluorescent lamps with a minimum color rendering index (CRI) of 85 and a color temperature of 4100 ºK.
   - Use enclosed[118] “high bay” pulse-start metal-halide[119] 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.[120]
2. Where luminaires will be mounted 15 to 25 ft above the floor use “low bay” fluorescent or pulse-start metal-halide luminaires:

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117 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 abter a brief power interruption.

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

119 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.

120 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.

- 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 85 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 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.

N. Space luminaires at approximately 0.65 times the maximum spacing to mounting height ratio to reduce the effects of a single lamp failure.[121]

O. 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.[122]

P. Use materials and installation methods described in LANL Master Specifications Section 26 5100, *Interior Lighting*.

7.3 Lighting Control

A. For all new buildings and renovation areas in existing buildings design lighting controls that comply with the requirements in ASHRAE/IES Standard 90.1.[123]

B. For all lighting control device replacements in existing buildings, design lighting controls that comply with the requirements in ASHRAE/IES Standard 90.1.[124]

C. Design occupancy sensing switching for all spaces with ceiling high partitions including the following spaces:[125]

- Private offices
- Laboratories
- Computer rooms
- File rooms
- Utility 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).

121 Refer to 5.2.3.1 in IES RP-7-01.
122 Refer to 3.7 in IES RP-7-01.
123 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.
124 Requirement in Section 4of ASHRAE/IES Standard 90.1.
125 Occupancy sensor controls are adopted as the method for achieving the automatic lighting shutoff required in Section 9 of ASHRAE/IES Standard 90.1.

D. Adjust time-out settings for occupancy sensors to optimize energy saving, relamping cost, and customer satisfaction. The following optimal settings have been determined: [126]

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

E. 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.[127] 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.*

F. Dual-Level Control

1. Use dual-level light switching or dimmer control in areas 100 square feet and larger.[128]
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.[129] *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.*

G. 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.*

H. In spaces with more than one personnel entrance, design the lighting controls so any required manual control will be available at each entrance.[130]

I. Use materials and installation methods described in LANL Master Specification Section 26 2726, *Wiring Devices*.

7.4 Installation

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

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[126] 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.

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

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

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

[130] Refer to Chapter 16 in the IES Lighting Handbook.

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.[131]

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

D. Install interior lighting systems in accordance with the manufacturer's instructions, LANL Master Specifications Section 26 5100, *Interior Lighting*, and the following standards:

1. NECA/IES 500, *Recommended Practice for Installing Indoor Commercial Lighting Systems*.
2. NECA/IES 502, *Recommended Practice for Installing Industrial Lighting Systems*.

8.0 EXIT AND EMERGENCY LIGHTING

8.1 General

A. Design emergency lighting and marking of means of egress in accordance with the *National Electrical Code*,[132] the *International Building Code*,[133] and NFPA 101 *Life Safety Code*.[134]

B. Perform lighting calculations using appropriate procedures[135] as outlined in the IES *Lighting Handbook*.

8.2 Emergency Lighting Unit Equipment

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.[136]
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.[137] 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.[138] Review such applications with the Electrical Chapter POC.

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131 Refer to NEC Article 604.
132 Refer to NEC Article 700.
133 Refer to Sections 1006 and 1011 in the International Building Code.
134 Refer to Chapter 7 in NFPA 101, *Life Safety Code*.
135 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.
136 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.
137 Emergency lighting equipment is standardized and cord-connected to facilitate maintenance.
138 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.

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 days and have a visual status indicator to indicate any failure.[139] *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.[140]

D. Use materials and installation methods described in LANL Master Specifications Section 26 5200, *Emergency Lighting*.

8.3 LED Emergency Exit Signs

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[141] LED lamps producing a minimum luminance of 8.6 cd/m^2.[142]

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[143]; 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 serving normal lighting in the area and ahead of any local switches. In the lighting panelboards clearly identify the branch circuits that serve emergency exit signs.[144]

E. Use materials and installation methods described in LANL Master Specifications Section 26 5200, *Emergency Lighting*.

8.4 Non-Powered Exit Signs

A. After December 31, 2008 do not use self-luminescent (tritium) exit signs for any purpose except in structures that require exit signs but do not have electrical power.[145]

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

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.[146]

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139 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

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

141 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.

142 Refer to Chapter 25 in the IES Lighting Handbook.

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

144 Required by Article 700 in the NEC.

145 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 that for a self-luminous exit sign.

146 ESM variance request on self-luminous exit sign replacements approved on 3/31/04.

C. Photoluminescent exit signs can only be used at locations meeting the following criteria: [147]

1. The face(s) of the sign will be continuously illuminated to not less than 5 footcandles 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. Replace self-luminous (tritium) exit signs and photoluminescent exit signs with LED emergency exit signs when lighting systems are replaced or renovated. [148]

E. Use materials and installation methods described in LANL Master Specifications Section 26 5200, *Emergency Lighting*.

9.0 EXTERIOR BUILDING LIGHTING

9.1 Selection

A. Design building-mounted safety and security lighting for exterior doors, stairways, loading docks, and mechanical equipment yards, plus parking lots and pedestrian walkways located adjacent to the building.[149]

B. Perform lighting calculations using procedures outlined in the IES *Lighting Handbook*. Use point-by-point methods for exterior applications.[150]

C. Select exterior lighting systems following guidance in the IES *Lighting Handbook.*[151]

D. Minimize the number of lamp and ballast types. [109]

E. Use high-efficiency, low maintenance luminaires (*e.g. high-pressure sodium or LED*) with cut-off type distribution that complies with the State of New Mexico “Night Sky Protection Act” [152]. *The International DarkSky 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.[153]

G. Use materials and installation methods described in LANL Master Specifications Sections 26 5100, *Interior Lighting*, and 26 5200, *Exterior Lighting*.

9.2 Control

A. Design exterior building lighting controls that comply with the requirements in ASHRAE/IES Standard 90.1. [154]

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147 Refer to UL 924 supplement SG.
148 Recommended practice for signal reference grids in Chapter 8 of IEEE 1100.
149 Refer to Chapter 26 in the IES Lighting Handbook.
150 Refer to Chapter 10 in the IES Lighting Handbook.
151 Refer to Chapter 26 in the IES Lighting Handbook.
152 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.
153 Refer to Chapter 26 in the IES Lighting Handbook.
154 Refer to Section 9 in ASHRAE/IES Standard 90.1.

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.

C. Use materials and installation methods described in LANL Master Specifications Section 26 5200, *Exterior Lighting*.

9.3 Installation

Install exterior lighting systems in accordance with the manufacturer's instructions, LANL Master Specifications Section 26 5200, *Exterior Lighting*, 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*
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.	David W. Powell, *ES-DE*	Kirk Christensen, *CENG*

		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.		
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*