CONSENSUS STATEMENT

Recommended standards for newborn ICU design

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INTRODUCTION

The creation of formal planning guidelines for newborn intensive care units (NICUs) first occurred when *Toward Improving the Outcome of Pregnancy* was published in 1976 [1] This landmark publication, written by a multidisciplinary committee and published by the March of Dimes, provided a rationale for planning and policy for regionalized perinatal care, as well as details of roles and facility design. Since then, the American Academy of Pediatrics (AAP) and American College of Obstetricians and Gynecologists (ACOG) have published several editions of their comprehensive *Guidelines for Perinatal Care* [2], and The American Institute of Architects has likewise published several editions of their *Guidelines for Construction of Hospital and Healthcare Facilities* [3].

The purpose of this committee is to complement the above documents by providing healthcare professionals, architects, interior designers, state healthcare facility regulators, and others involved in the planning of NICUs with a comprehensive set of standards based on clinical experience and an evolving scientific database.

With the support of Ross Products Division/Abbott Laboratories, a multidisciplinary team of physicians, nurses, state health planning officials, consultants, and architects reached a consensus on the first edition of these recommendations in January 1992. The document was sent to all members of the American Academy of Pediatrics Section on Perinatal Pediatrics to solicit their comments, and we also sought input from participants at the 1993 Parent Care Conference and at an open, multidisciplinary conference on newborn ICU design held in Orlando in 1993. Subsequent editions of these recommended standards were then developed by consensus committees in 1993, 1996, 1999, 2002, 2006, 2007, 2012, and 2019 under the auspices of the Gravens Conference.

Various portions of these recommended standards have now been adopted by the American Institute of Architects/Facilities Guidelines Institute *Guidelines* [3], the AAP/ACOG *Guidelines* [2], and by standards documents in several other countries. In the future, we will continue to update these recommendations on a regular basis, incorporating new research findings, experience, and suggestions. It is our hope this document will continue to provide the basis for a consistent set of standards that can be used by all states and endorsed by appropriate national organizations, and that it will also continue to be useful in the international arena. While many of these standards are minimums, the intent is to optimize design within the constraints of available resources and to facilitate excellent health care for the infant in a setting that supports the central role of the family and the needs of the staff. Decision makers may find these standards do not go far enough, and resources may be available to push further toward the ideal.

APPLICATION OF THESE STANDARDS

Unless specified otherwise, the following recommendations apply to the newborn intensive care built environment, although most have broader applications for the care of ill infants and their families.

Where the word *shall* is used, it is the consensus of the committee participants that the standard is appropriate for future NICU constructions. We recognize that it may not be reasonable to apply these standards to existing NICUs or those undergoing limited renovation.

We also recognize the need to avoid statements requiring mandatory compliance unless a clear scientific basis or consensus exists. The standards presented in this document address only those areas where we believe such data or consensus is available.

Individuals and organizations applying these standards should understand that this document is not meant to be all-encompassing. It is intended to provide guidance for the planning team to apply the functional aspects of operations with sensitivity

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to the needs of infants, families, and staff. The program planning and design process should include research, evidence-based recommendations, and materials, with objective input from experts in the field in addition to the internal interdisciplinary team that includes families who have experienced newborn intensive care. The design should creatively reflect the vision and spirit of the infants, families, and staff of the unit. The program and design process should include:

Development of vision and goals for the project
Education on design planning and processes for changing organizational culture
Review of articles on patient- and family-centered care, individualized developmentally supportive care, teambuilding, evidence-based design, facility planning, and other relevant aspects of clinical practice.
Visits to new and renovated units
Vendor Fairs
Program Planning
Space planning, including methods to visualize 3-D space
Operations planning, including traffic patterns, functional locations, and relationship to ancillary services
Interior planning
Surface materials selection
Review of blueprints, specifications, and other documents
Construction of working mock-ups with simulation opportunities
Preparation and planning for change in practice for staff and families in the new unit
Building and construction
Post-construction verification, simulation, and remediation
Post-occupancy evaluation

SUBSTANTIVE CHANGES—10TH EDITION

Standards 6 and 7 are now combined with parallel information about required space in Multi-bed and Private (Single Family) rooms in the Revised Standard 6. This combination also shifts the numbering of each standard that follows. Extra-corporeal membrane oxygenator (ECMO) and special care rooms are also referenced and space-defined.

Standard 7 (previously Standard 8) on Couplet Care Rooms now requires hospitals that offer both an obstetric service and NICU to provide couplet care rooms equipped to provide for intensive care of the newborn and post-partum care for the mother in the same room or suite.

Standard 9 (previously Standard 10) redefines size and requirements for separate hallways in alignment with FGI minimum standards for similar spaces. The ECMO portion was moved to Standard 6. It is also made clear that procedure rooms are not "areas" but instead enclosed rooms that provide for a higher level of environmental control.

Standard 15 (previously Standard 16) regarding Support Spaces for Ancillary Services addresses the addition of infant MRI for space and floor weight capacity.

Standard 20 (previously Standard 21) on Wall Finishes introduces the topic of color consideration appropriate for local culture and climate.

Standard 29 (previously Standard 30) expands the Interpretation to give more guidance in providing high-quality usability testing.

THE NEWBORN INTENSIVE CARE UNIT

The American Academy of Pediatrics has defined NICU levels of care [2] based primarily on the availability of specialized equipment and staff, but many NICUs often encompass both intensive and step-down or intermediate care. These recommended standards are meant to apply to level III and IV NICU care.

For the purposes of this document, *newborn intensive care* is defined as care for medically unstable or critically ill newborns requiring constant nursing, complicated surgical procedures, continual respiratory support, or other intensive interventions.

Intermediate and level II NICU care includes care of ill infants requiring less constant nursing but does not exclude respiratory support. When an intensive care nursery is available, the intermediate nursery serves as a "step down" unit from the intensive care area. When hospitals mix infants of varying acuity, requiring different levels of care in the same area, intensive care design standards shall be followed to provide maximum clinical flexibility.

STANDARDS

Delivery room standard

Infant resuscitation/stabilization areas. Space for infant resuscitation/stabilization shall be provided within operative delivery rooms and within Labor/Delivery/Recovery (LDR), Labor/Delivery/Recovery/Post-partum (LDRP) rooms, and other non-operative delivery rooms. Delivery rooms may directly connect to nursery or Newborn ICU (NICU) space via pass-through windows or doors. The ventilation system for each delivery and resuscitation room shall be designed to control the ambient temperature between 72–78 degrees Fahrenheit (22–26 degrees Centigrade) during the delivery, resuscitation, and stabilization of a newborn. Such space shall also be designed to meet lighting and acoustical standards detailed in standards 23, 24, 25, 26, and 28.

Specific recommendations for each location where infant resuscitation or stabilization occurs are as follows:

Operative delivery rooms

Recommendations for operating rooms intended for use by NICU patients (Standard 9) shall be followed with these exceptions:

- A minimum clear floor area of 80 square feet (7.5 square meters) for the infant shall be provided in addition to the area required for other functions.
- 3 oxygen, 3 air, 3 vacuum, and 12 simultaneously accessible electrical outlets shall be provided for the infant and shall comply with all specifications for these outlets described in NICU Standard 10.
- The infant space may not be omitted from the operative delivery room(s) when a separate infant resuscitation/stabilization room is provided.

LDR, LDRP, or other non-operative delivery rooms

- A minimum clear floor area of 40 square feet (3.7 square meters) shall be provided for infant space. This space may be used for multiple purposes including resuscitation, stabilization, observation, exam, sleep or other infant needs.
- 1 oxygen, 1 air, 1 vacuum, and 6 simultaneously accessible electrical outlets shall be provided for the infant in addition to the facilities required for the mother.
- The infant space may not be omitted from the LDR, LDRP, or non-operative delivery room when a separate infant resuscitation/stabilization room is provided.

Pass-through windows and doors

- Windows and doors shall be designed for visual and acoustical privacy and shall allow easy exchange of an infant between personnel.

- When an operative delivery room is equipped with a pass-through window or door, it shall have positive pressure so that air flows out to the infant room when the window or door is opened.

Interpretation:

All delivery rooms (operative and non-operative) are required to have separate resuscitation spaces and outlets for infants. This space provides an acceptable environment for most uncomplicated term infants but may not support the optimal management of infants who will become NICU patients.

Some term infants and most preterm infants are at greater thermal risk and often require additional personnel, equipment, and time to optimize resuscitation and stabilization.

They are essentially NICU patients from the time of delivery and would therefore be optimally managed in a space designed to NICU standards. The appropriate resuscitation/stabilization environment should be provided. Providing it in each delivery room allows parents to be aware of the staff's efforts to revive and care for their infant before transport to the NICU. Providing ongoing support in a designated admission room or within the NICU with infant transfer via pass-through windows or doors offers efficiencies for staff, an environment designed for infants, and immediate access to all necessary equipment and supplies. Concerns about exposure to infection due to an opening into an operative room from a non-sterile (NICU) area are addressed by designing airflow out of the sterile room when windows and doors are opened.

The provision of appropriate temperature for delivery room resuscitation of high-risk preterm infants is vital to their stabilization. While lower temperatures are often more comfortable for gowned attendants, the needs of the high-risk infant must take priority. It is also essential that these appropriate ambient temperatures can be achieved within a short time frame since many high-risk deliveries occur with little warning.

The functional plan should facilitate skin-to-skin care immediately after delivery, including accommodation for family members and necessary equipment.

Since many of the higher-risk patients are delivered in operative delivery rooms, the operative room minimums should be greater than the minimum standards for LDRs or LDRPs. If a hospital serves a predominantly high-risk perinatal population, the hospital is encouraged to exceed the minimum standards.

Equipment storage may be best provided by a wall-hung board or other suitable technique to allow ready visibility and access to all needed resuscitation equipment.

NEWBORN ICU STANDARDS

Standard 1: Unit configuration

The NICU design shall be driven by systematically developed program goals and objectives that define the purpose of the unit, service provision, space utilization, projected bed space demand, staffing requirements, and other basic information related to the mission of the unit. Design strategies to achieve program goals and objectives shall address the medical, developmental, educational, emotional, and social needs of infants, families, and staff. The design shall allow for flexibility and creativity to achieve the stated objectives.

The NICU shall contain sufficient single-family rooms to meet the needs of parents who expect to stay with their babies, including families of twins or higher-order multiples.

Interpretation: Program goals and objectives congruent with the philosophy of care and the unit's definition of quality should be developed by a planning team. This team should include, among others, healthcare professionals, families whose infants have experienced newborn intensive care, administrators, and design professionals.

The program goals and objectives should include a description of those services necessary for the complete operation of the unit and address the potential need to expand services to accommodate increased demand.

Choosing the appropriate mix of single-family rooms along with other patient bed arrangements (e.g., multiple-bed "open-bay" rooms, couplet care rooms) will require careful evaluation of these needs over the intended lifespan of the NICU. Patient care spaces, whether single-family rooms or in groupings, should be configured in a way that promotes optimal monitoring, response by caregivers to patient and family needs, and social interaction. The specific approaches to achieving individualized environments are addressed in subsequent sections.

Now that parental engagement has been understood as important to the infant's well-being, a systematic approach to identifying parental needs and barriers to parental presence is essential. In order to be present and functional, parents need (at a minimum) rest, good nutrition, psychosocial and educational support, access to social networks, and a way to address everyday needs efficiently. In the context of the NICU, that may translate into providing services like WiFi, access to laundry facilities, places to sleep, and on-site counseling.

Standard 2: NICU location within the hospital

The NICU shall be a distinct area within the health care facility, with controlled access and a controlled environment.

The NICU shall be located within a space designed for that purpose. It shall provide effective circulation of staff, family, and equipment. Traffic to other services shall not pass through the unit.

The NICU shall be in close and controlled proximity to the area of the hospital where births occur. When obstetric and neonatal services must be on separate floors of the Hospital, an elevator located adjacent to the units with priority call and controlled access by keyed operation shall be provided for service between the birthing unit and the NICU.

Units receiving infants from other facilities shall have ready access to the hospital's transport receiving area and shall designate a space for transport equipment.

Interpretation: The purpose of this standard is to provide safe and efficient transport of infants while respecting their privacy. Accordingly, the NICU should be a distinct, controlled area immediately adjacent to other perinatal services, except in those local situations (e.g., free-standing children's hospitals) where exceptions can be justified.

Transport of infants within the hospital should be possible without using public corridors.

Standard 3: Family entry and reception area

The NICU shall have a clearly identified entrance and reception area for families. Families shall have immediate and direct contact with staff when they arrive at this entrance and reception area.

Interpretation: The design of this area should contribute to positive first impressions for families and foster the concept that families are important members of their infant's healthcare team, not visitors. Facilitating contact with staff will also enhance security for infants in the NICU. Equipment and supplies should not be stored at the entry to the NICU.

This area should have lockable storage facilities for families' personal belongings (unless provided elsewhere), and may also include a handwashing and gowning area.

Standard 4: Signage and art

Signage and art at the entrance and throughout the NICU shall reflect the diversity of the community served and shall convey to families that they are welcomed and supported as essential to the care of their infants. This information shall be provided to families immediately after entering the NICU in languages and/or symbols understandable to the diversity of communities served.

Interpretation: Signage and art at the entrance to the NICU create powerful first impressions. They reinforce the importance of families in care, care planning, and decision-making for their infants. Families should not be labeled as "visitors" and hence inconsequential to care and outcomes.

Signage should convey that parents define their family and how they wish for them to be involved in care. Parents should determine who can best support them through their NICU journey.

Signage should consistently reflect actual policy and practice and encourage family participation in care, care planning, decision-making, and key care processes such as rounds and nurse change of shift reports.

Temporary signage, such as cold and flu season signs, should also use the language of partnership and not power—"During cold and flu season we will work together with families to keep babies safe."

Signage and art at the entrance and throughout the NICU facilitate ongoing connections with communities when they are familiar with the diversity of families served. They promote hope and confidence when messages and art feature families caring for their premature infants.

Standard 5: Safety/infant security

The NICU shall be designed as part of an overall security program to protect the physical safety of infants, families, and staff in the NICU. The NICU shall be designed to minimize the risk of infant abduction.

Interpretation: Because facility design significantly affects security, it should be a priority in the planning for the renovation of an existing unit or a new unit. Care should be taken to limit the number of exits and entrances to the unit.

Control station(s) should be located within close proximity and direct visibility of the entrance to the infant care area. The control point should be situated so that all visitors must walk past the station to enter the unit. The need for security should be balanced with the need for comfort and privacy of families and their infants.

Technological devices can be utilized in flexible and innovative manners within the design of the multiple-bed or single-infant room NICU schematic. Such technology, when utilized in conjunction with the thoughtful planning of the traffic patterns to/from and within the NICU space, support areas, and family space, can facilitate a safe, yet open family-friendly area.

Standard 6: Minimum space, clearance, and privacy requirements for the infant space

Multi-bed infant rooms. Each infant space shall contain a minimum of 150 square feet (14 square meters) of clear floor space, excluding handwashing stations, columns, and aisles (see Glossary). Within this space, there shall be sufficient furnishing to allow a parent to stay seated, reclining, or fully recumbent at the bedside. There shall be an aisle adjacent to each infant space with a minimum width of 4 feet (1.2 meters) in multiple-bed rooms. When single infant rooms or fixed cubicle partitions are utilized in the design, there shall be an adjacent aisle of not less than 8 feet (2.4 meters) in clear and unobstructed width to permit passage of equipment and personnel.

Multiple-bed rooms shall have a minimum of 8 feet (2.4 meters) between infant beds. There shall be provision for visual privacy for each bed, and the design shall support speech privacy at a distance of 12 feet (3.6 meters).

Private (single-family) rooms. Rooms intended for the use of a single infant and his/her family shall conform to the requirements for infant spaces designated elsewhere in these standards, with the following exceptions:

- Minimum size shall be no less than 180 square feet (16.7 square meters) of clear floor area.
- An outside window is not required (see Standard 26 for further specifics).
- The requirement for wireless monitors and communication devices shall be identical to that described for isolation rooms (Standard 8).
- Each room shall be designed to allow visual and speech privacy for the infant and family, including for skin-to-skin care, breastfeeding, and pumping.

Family space shall be designated and include, at a minimum:

- comfortable reclining chair suitable for kangaroo/skin-to-skin care
- A recumbent sleep surface for at least one parent
- A desk or surface suitable for writing and/or use of a laptop computer
- At least four electrical outlets for the use and charging of electronic devices.
- No less than 6 cubic feet (0.2 cubic meters) of storage space
- Staff space shall be designated and include, at a minimum:
- A work surface of no less than 6 square feet (0.6 square meters)
- A charting surface of no less than 3 square feet (0.3 square meters)
- Supply storage of no less than 30 cubic feet (0.85 cubic meters).

NOTE: The above requirements can be met by any combination of fixed and portable casework desired, but all storage must be designed for quiet operation.

Specialized infant care space or rooms. Infant care space designed to accommodate specialized bedside procedures that require additional space for equipment, staff, and other needs (e.g., extracorporeal membrane oxygenation, or ECMO, space-intensive bedside surgical procedures that require higher minimum space standards for staff and equipment) shall have a minimum clear floor area of 225 square feet (21 square meters) per infant in multi-bed rooms and 300 square feet (27.9 square meters) in single-bed rooms.

Interpretation: These numbers are minimums and often need to be increased to reflect the complexity of care rendered, bedside space needed for parenting and family involvement in care, and privacy for families.

The width of aisles in multiple-bed rooms should allow for easy movement of all equipment that might be brought to the infant's bedside, as well as easy access to a maternal bed. The width of the corridors or aisles outside single infant rooms or infant spaces designed with permanent cubicle partitions should allow for simultaneous passage of two such items as mandated by state and federal architectural and fire codes.

The need for visual and acoustic privacy for infants and families should be addressed not only in the design of each bed space but also in the overall unit design—for example, by minimizing traffic flow past each bed.

Private (single-family) rooms allow improved ability to provide individualized and private environments for each baby and family when compared to multi-patient rooms. In order to provide adequate space at the bedside for both caregivers and families, however, these rooms need to be somewhat larger than an infant space in an open multi-bedroom design, and they must have additional bedside storage and communication capabilities in order to avoid isolation or excessive walking of caregivers. A sleep surface for a second parent, a bathroom, a shower, and lockable storage for parents should be provided whenever possible.

While sleep space for two parents is recommended, if that sleep space is part of the infant's room, parents may not always experience good quality sleep due to noise and staff activity. Since

parents are already at risk of mental health issues related to their infant's hospitalization, protecting the quality of their sleep is important. Consider separating the infant space from the parent sleep space if possible, and/or providing additional hoteling space elsewhere on campus for parents. The goal of providing sleep space for parents is to remove barriers to their participation and to facilitate attachment, but that should not be done at the expense of their well-being. Parents should feel invited but not compelled to stay.

Although desirable, it may not be possible to provide a window for each room due to a finite amount of outside wall area. It is most important to utilize the available window area first for the gathering spaces used by family and caregivers, and then secondarily for patient rooms.

Standard 7: Couplet care rooms

Any hospital that offers both an obstetrical delivery service and neonatal intensive care shall include an adequate number of couplet care rooms equipped to provide both intensive care for the newborn and post-partum care for the mother in the same room or suite. This requirement does not apply to mothers who require specialized care after delivery such as treatment for unstable hypertension or respiratory failure, or to infants who require care such as ECMO or isolation that cannot be provided in a conventional NICU room. An assessment of the appropriate quantity of couplet care rooms shall be conducted to identify an adequate number.

When a room is provided in the NICU, post-partum, or LDRP Unit that allows a hospitalized mother and NICU patient to be cared for in the same room, the room shall have the following:

- Couplet Care Room in the NICU or Post-partum Unit: Minimum clear floor area of 150 square feet (14 square meters) for the NICU infant and 150 square feet for the mother.
- LDRP Room: 405 square feet 37.6 square meters) for combined mother and NICU patients.
- Minimum clearances shall be provided as follows:
  - Post-partum patient rooms: 4 feet (1.2 meters) at the foot of the bed.
  - NICU Couplet Care Rooms: 1 foot (0.3 meters) from the head of the bed to the wall, 4 feet from the foot of the bed to the wall or other obstruction, and 8 feet (2.4 meters) between beds.
  - LDRP Clearances: Six feet (1.8 meters) at the foot of the bed, 5 feet (1.5 meters) on the transfer side of the bed to a wall or fixed obstruction, and 4 feet on the non-transfer side.
- Family and staff space shall be provided as specified in Standard 6 (Single-Family rooms).
- Each patient room with a hospitalized adult patient shall be provided with natural light by means of a window to the outside. In new construction, the windowsill height in the patient rooms shall be a maximum of 36 inches (0.9 meters) above the finished floor.
- Each patient room with a hospitalized adult patient shall have direct access to an enclosed toilet room with a shower and handwashing station.
- There shall be a handwashing station in the patient room in addition to that in the toilet room.
- Each patient room shall have a separate lockable wardrobe, closet, or locker suitable for garments and for storing personal effects.

Interpretation: Infants born with medical problems have historically been separated from their mothers after birth. This model provides integrated hospitalized mother and neonate care. The benefits include early maternal attachment, skin-to-skin care, access to breast milk, and participation in care, among others [4].

This model provides a platform for staff to consider the interdependent needs of the mother and infant(s) as a couple in addition to each patient's individual needs. The Standard maintains the square feet for each patient type with a neutral impact on minimum space and clearances.

The required assessment of the adequate quantity of couplet care rooms for the hospitalized mother and NICU patient should include a collection of information that identifies the eligible patient population, lengths of stay, required staff, and other relevant factors to project future room needs and support the building design.

Other facility considerations include providing access to clean supplies, linen, medication, and equipment storage for both adult and neonatal patients.

Standard 8: Airborne infection isolation room(s)

An airborne infection isolation room shall be available for NICU infants and shall provide a minimum of 180 square feet (16.7 square meters) of clear floor space, excluding the entry work area. A hands-free handwashing station for hand hygiene and areas for gowning and storage of clean and soiled materials shall be provided near the entrance to the room. Ventilation systems for isolation rooms shall be engineered to have negative air pressure with air 100% exhausted to the outside and shall meet acoustic standards for infant rooms (see Standard 28 for specifics). Airborne infection isolation room perimeter walls, ceilings, and floors, including penetrations, shall be sealed tightly so that air does not infiltrate the environment from the outside or from other airspaces.

Airborne infection isolation rooms shall have self-closing devices on all room exit doors. An emergency communication system and remote patient monitoring capability shall be provided within the airborne infection isolation room.

Airborne infection isolation rooms shall have observation windows with internal blinds or "smart" glass for privacy. Placement of windows and other structural items shall allow for ease of operation and cleaning.

Airborne infection isolation rooms shall have a permanently installed visual mechanism to constantly monitor the pressure status of the room when occupied by a patient with an airborne infectious disease. The mechanism shall continuously monitor the direction of the airflow.

Interpretation: An airborne infection isolation room adequately designed to care for ill newborns should be available in any hospital with a NICU. In most cases, this is ideally situated within the NICU, but in some circumstances, utilization of an airborne infection isolation room elsewhere in the hospital (e.g., in a pediatric ICU) would be suitable.

At least one single-occupancy isolation room should be available for any infant with a suspected airborne infection. A space within the NICU should also be available to safely cohort a group of infants infected with or exposed to a common airborne pathogen.

When not used for isolation, these rooms may be used for the care of non-infectious infants and other clinical purposes.

Turbulence attendant to high air exchange rates can result in unacceptable levels of background noise in airborne infection isolation rooms. Such levels result in speech interference, annoyance, and physiologic responses typical of noise exposure for adults and infants. Specific attention is required, therefore, to the design of the heating/ventilation/air-conditioning ductwork and to washable acoustic surfaces on the walls and ceilings to ensure that sound levels meet the Standard in these rooms. Glass partitions should be limited to that which is actually necessary for safe visualization.

Proportional amounts of acoustically absorptive and acoustically reflective surfaces should be appropriate to achieve greater than 25% sound absorption.

Standard 9: Operating and procedure rooms intended for use by newborn ICU patients

Operating rooms in healthcare facilities where infant procedures may be performed shall be constructed to operating room specifications except for the following modifications:

Assuming the infant's eyes are shielded (eye patches) while in the operating room, no changes to the IES guidelines for operating rooms [5] are required. However, light sources meeting the values identified in Standard 23 are recommended.

Laminar flow diffusers over the surgical bed shall be set at the low end of the air velocity range (approximately 25 ft/min) and balanced with the surrounding slot diffuser air curtain to minimize convective and evaporative heat and water loss from higher airflow onto the infant. In addition, ambient temperature and humidity shall be adjustable into the range of 72–78° F (22 to 26 °C) with a relative humidity of at least 30%.

The acoustic environment set forth in Standard 28 shall be one of the bases for all design choices.

Procedure rooms within the newborn ICU. Where provided, Specialized procedure spaces or rooms within the NICU shall be constructed to achieve all of the above, as well as all of the requirements for an infant bed space elsewhere in these Recommended Standards, except for the following modifications:

Each procedure room must be in a semi-restricted area, physically separated from other areas so that during surgery or procedures patient and staff flow may be strictly controlled. Air flow must be designed so as to not disrupt the air curtain around the surgical field, and shall be adjustable so as to be able to increase to 15 changes/h during procedures, then return to baseline values set forth in this Standard. Where anesthetic gas will be used in this room, a waste anesthetic gas disposal (WAGD) scavenging system to vent waste inhalation anesthesia and analgesia gases is required. HVAC equipment shall be of a type that minimizes the need for maintenance within the room.

Procedure rooms shall have a minimum clear floor area of 180 square feet (16.7 square meters) exclusive of built-in shelves or cabinets, handwashing stations, and columns. Rooms where procedures will require more personnel and large equipment shall be sized to accommodate these needs including additional space for equipment and staff needed for resuscitation and other emergencies. When laser procedures occur in these rooms, the rooms shall be designed to comply with The Association of Surgical Technologists' Standards of Practice for Laser Safety [6].

Where infants having surgery in the NICU recover in their own beds no separate recovery or post-anesthesia areas are required.

Separate sterile corridors and work areas for the storage and processing of surgical instruments leading to the procedure room are not required. However, support areas for storage of clean and sterile surgical supplies shall be provided, and a handwashing station shall be provided near the entrance to each procedure room or in the procedure room.

Ambient lighting recommendations set forth in Standard 23 shall be followed except where higher illuminances are required as set forth in IES recommendations for operating rooms [5]. Increased ambient lighting must still be adjustable and indirect.

Interpretation: Standard operating room environments may be temporarily modified to better accommodate term infants requiring surgery, but cannot be made optimal for some term and preterm infants, nor can the problems associated with transporting less stable infants away from the intensive resources of the NICU be avoided. There is sufficient experience to conclude that certain procedures can be performed in the NICU without compromising patient safety or outcomes.

Standard 10: Electrical, gas supply, and mechanical needs

Mechanical requirements at each infant bed, such as electrical and gas outlets, shall be organized to ensure safety, easy access, and maintenance.

There shall be a minimum of 20 simultaneously accessible electrical outlets. The minimum number of simultaneously accessible gas outlets is: Air 3, Oxygen 3, and Vacuum 3.

There shall be a mixture of emergency and normal power for all electrical outlets per current National Fire Protection Association recommendations [7].

Interpretation: A system that includes easily accessible raceways for electrical conduit and gas piping, workspace, and equipment placement is recommended because it permits flexibility to modify or upgrade mechanical, electrical or equipment features. All outlets should be positioned to maximize access and flexibility and minimize repetitive movements such as bending and stretching by the staff. Standard duplex electrical outlets may not be suitable, since each outlet may not be simultaneously accessible for oversized equipment plugs. The number of electrical, gas, and suction outlets specified is a minimum; access to more may be necessary for critically ill infants. This area should also include communication devices, supply storage, and charting space, resulting in an efficient, organized, and self-contained workstation around the infant.

Standard 11: Ambient temperature and ventilation

The NICU shall be designed to provide an air temperature of 72 °F to 78 °F (22–26 °C) and relative humidity of 30–60% while avoiding condensation on wall and window surfaces.

A minimum of six air changes per hour is required, with a minimum of two changes being outside air.

The ventilation pattern shall inhibit particulate matter from moving freely in the space, and intake and exhaust vents shall be situated to minimize drafts on or near the infant beds. Ventilation air delivered to the NICU shall be filtered with at least the efficiency specified in the FGI Guidelines [3]. Filters shall be located outside the infant care area so they can be changed easily and safely.

Interpretation: The airflow pattern should be at low velocity. Ductwork should be designed to minimize noise. Registers and their placement should minimize drafts, noise, and airborne particulate matter. A HEPA filtration system may provide improved infection control for immunocompromised newborns.

Because a regular maintenance program is necessary to ensure that systems continue to function as designed after occupancy, NICU design should attempt to maximize the ease of maintenance while minimizing its cost.

Standard 12: Handwashing

Every infant bed, whether in a single or multiple-bed room, shall be within 20 feet (6 meters) of a hands-free handwashing station. Handwashing stations shall be no closer than 3 feet (0.9 meters) from an infant bed, clean supply storage, or counter/work surface unless a splashguard is provided.

Handwashing sinks shall be large enough to control splashing and designed to avoid standing or retained water. The minimum dimensions for a handwashing sink are 24 inches wide x 16 inches front to back x 10 inches deep (61 cm×41 cm x 25 cm) from the bottom of the sink to the top of its rim. The faucet shall be offset from the drain. There shall be no aerator on the faucet. Space for pictorial handwashing instructions shall be provided above all sinks. Space shall also be provided for soap and towel dispensers and for appropriate trash receptacles. Towel dispensers shall operate so that only the towel itself needs to be touched in the

process of dispensing, and constructed in such a fashion as to control noise as per Standard 28. Walls adjacent to handwashing sinks shall be constructed of non-porous material.

Handwashing facilities located at a level where they can be used by people in wheelchairs shall be available in the NICU.

Separate receptacles for biohazardous and non-biohazardous waste shall be available.

Interpretation: Proper hand hygiene is a key component in the prevention and reduction of the spread of infection in healthcare settings. Alcohol-based hand rubs (ABHR) have been shown to be more effective than soap-and-water handwashing in decontaminating hands that are not visibly soiled. ABHR dispensers can be easily located at sites where hand hygiene is required. Handwashing sinks are also required in close proximity to infant spaces to be used when hands are soiled or contaminated with body fluids.

Sinks for handwashing should not be built into counters, and the rim should be either less than two inches wide or rounded to discourage placement of clean items on a contaminated surface. Sink location, construction material and related hardware (paper towel and soap dispensers) should be chosen with durability, ease of operation, ease of cleaning, and noise control in mind. Non-absorbent wall material should be used around sinks to prevent the growth of mold on cellulose material.

Local, state, and federal regulatory agencies dictate what healthcare-generated waste is biohazardous or non-biohazardous and appropriate disposal methods that are dependent on the type of waste. Depending upon the jurisdiction, biohazard signage may need to be affixed.

Standard 13: General support space

Distinct facilities shall be provided for clean and soiled utilities, medical equipment storage, and unit management services.

Clean Utility/Holding Area(s): For storage of supplies frequently used in the care of newborns.

Soiled Utility/Holding Room: Essential for storing used and contaminated material before its removal from the care area. Unless used only as a holding room, this room shall contain a counter and a wall-mounted hands-free handwashing station separate from any utility sinks. The handwashing station shall have hot and cold running water that is turned on and off by hands-free controls, soap and paper towel dispensers, and a covered waste receptacle with foot control.

The ventilation system in the soiled utility/holding room shall be engineered to have negative air pressure with air 100% exhausted to the outside. The soiled utility/holding room shall be situated to allow the removal of soiled materials without passing through the infant care area.

A designated area for the collection of recyclable materials used in the NICU shall be established. This area shall measure at least one square foot per patient bed and be located outside the patient care area.

Charting/Staff Work Areas: Charting space at each bedside shall be provided. An additional separate area or desk for tasks such as compiling more detailed records, completing requisitions, and telephone communication shall be provided in an area acoustically separated from the infant and family areas. Dedicated space shall be allocated as necessary for electronic medical record keeping within infant care areas.

Interpretation: *Storage areas:* A three-zone storage system is desirable. The first storage area should be the central supply department of the hospital. The second storage zone is the clean utility area described in the standard; it should be adjacent to and acoustically separated from the infant care and family areas. Routinely used supplies such as diapers, formula, linen, cover gowns, charts, and information booklets may be stored in this space. There should be at least 8 cubic feet (0.22 cubic meters) for each infant for secondary storage of syringes, needles, intravenous infusion sets, and sterile trays.

There should also be at least 18 square feet (1.7 square meters) of floor space allocated for equipment storage per infant in intermediate care, and 30 square feet (2.8 square meters) for each infant bed in intensive care. Total storage space may vary by unit size and storage system.

Easily accessible electrical outlets are desirable in this area for recharging equipment.

The third storage zone is for items frequently used at the infant's bedside. Bedside cabinet storage should be at least 16 cubic feet (0.45 cubic meters) for each infant in the intermediate care area and 24 cubic feet (0.67 cubic meters) for each infant in the intensive care area. Bedside storage should be designed for quiet operation.

Hospitals contribute significant waste each year to incinerators and landfills. This creates not only an environmental hazard but also conditions that are harmful to human health. Providing a designated collection area enables staff to separate and store collection waste such as paper, newsprint, corrugated cardboard, plastics, metals, batteries, fluorescent lamps, and glass to either facilitate existing hospital procedures for recycling or initiate a recycling system. Space within the designated collection area also may be used for the collection of medical supplies for distribution to hospitals or clinics in need of such materials.

Charting/staff work areas: A clerical area should be located near the entrance to the NICU so personnel can supervise traffic into the unit. In addition, there should be one or more staff work areas, each serving 8 to 24 beds. These areas will allow groups of 3–10 caregivers to congregate immediately adjacent to the infant care area for report, collaboration, and socialization without impinging on infant or family privacy. Infants' charts, computer terminals, and hospital forms may be located in this space.

The design of the NICU must incorporate the use of electronic medical record devices so that their use does not cause major disruption of the function of the unit or impinge on space designed for other purposes. Design considerations for digital workstations include ease of access for staff, patient confidentiality, infection control, and noise control, both with respect to that generated by the devices and by the traffic around them.

Laundry room: If laundry facilities for infant materials are provided, a separate laundry room can serve the functions of laundry and toy cleaning within the NICU. Infant clothing and the cloth covers of positioning aids should be laundered on a regular schedule and as needed. In addition, toys utilized by infants or siblings are required to be cleaned on a regular schedule for each infant and between infants. Space for a commercial-grade washer and dryer should be accommodated. The dryer should be vented through an outside wall. The placement of a commercial-grade dishwasher could promote the efficiency and effectiveness of the aseptic cleaning process for toys.

Standard 14: Staff support space

Space shall be provided within the NICU to meet the professional, personal, and administrative needs of the staff. Rooms shall be sized and located to provide privacy and to satisfy their intended function. Locker, lounge, private toilet facilities, and on-call rooms are required at a minimum.

Interpretation: Support elements can be defined as those that facilitate the provision of infant care and the well-being of the staff; they may account for at least one-third of the floor space of the entire unit.

Staffing areas are defined as space limited to use by staff members to meet personal, professional, and administrative needs. These areas include lockers, lounges, counseling, education and conference space, and on-call rooms that provide privacy and satisfy their intended function. Whenever possible, the staff lounge should provide access to daylight and views of nature.

Standard 15: Support space for ancillary services
Distinct support space shall be provided for all clinical services that are routinely performed in the NICU.

Counseling space. A minimum of one dedicated space shall be provided in the NICU to support counseling services for families and staff. This room(s) shall be sized to accommodate a minimum of three adults and an infant bed. This space shall have access from family and staff areas and provide acoustic and visual privacy. Furnishings shall include comfortable seating.

Interpretation: The emotional and psychological challenges for families and staff in the NICU setting are extensive. Space should be provided for the counseling support of these populations; in larger units, this may require the designation of two or more rooms. This space can be used for related counseling needs such as private space for interaction between families and social workers, and grieving spaces. Additional space for more family members might be appropriate. Consider the provision of oxygen and vacuum outlets if the presence of the baby in the room is desired. If the space is used frequently, consider separate rooms for staff and families. Staff should be aware that this space is dedicated to counseling and not to be used for other purposes such as staff meetings and storage. A visual system to indicate when the room is in use is recommended, as well as adequate soundproofing to ensure conversations are private and the impact of outside noise is minimized. Each unit should provide a sufficient number of counseling rooms to meet the needs for counseling and private conversations away from the bedside.

Milk preparation. Space for the preparation and storage of human milk, formula, and additives shall be provided within the unit or other location that is away from the bedside [8]. When a separate room for infant feeding preparation is not merited due to infrequency of need, commercial preparation off-premises, or other reasons, a separate area in the food services area or in the patient unit shall be designated for infant feeding preparation. Hospital food preparation design guidelines shall be followed.

When the functional program requires a separate room, the room shall include the following areas that can be separated in individual rooms or combined:

(a) Ante area
(b) Preparation area
(c) Storage space for supplies, formula, and both refrigerated and frozen breast milk.
(d) Clean-up area

To minimize contamination, the ventilation system should have a minimum filtration of 90% based on the American Society of Heating, Ventilation, and Air Conditioning Engineers standards or have a HEPA-forced air filtration system.

Provisions shall be included for human milk storage. Human milk may be stored in a designated space in the infant feeding preparation room and in designated spaces in the patient unit. If the refrigerator or freezer is located in the infant space or a hallway, the condenser noise shall not exceed 40 dBA.

Interpretation: Ancillary services such as (but not necessarily limited to) respiratory therapy, laboratory, pharmacy, radiology, developmental therapy, and specialized feeding preparation are common in the NICU. Distance, size, and access are important considerations when designing space for each of these functions. Satellite facilities may be required to provide these services in a timely manner.

Unless performed elsewhere in the hospital, a specialized feedings preparation area or room should be provided in the NICU, away from the bedside, to permit mixing of additives to breast milk or formula. The cleanliness of the floor surface, walls, and ceilings should be easily maintained. Floor drains are not recommended unless required by local code. Adequate sinks, electrical outlets, and storage should be provided based on the individual hospital facility needs. The use of a laminar flow hood is a decision that each hospital should make. Pharmacies are not required to use laminar flow hoods to prepare oral medications. Powdered formulas are not sterile, and preparing them under a laminar flow hood may not improve the sterility of the product. All water supplied for feeding preparation should meet Federal Standards for drinking water and be commercially sterile. Commercially sterile water is preferred because it has eliminated pathogenic and other organisms that, if present, could grow in the product and produce spoilage under normal conditions of handling and storage.

NICU magnetic resonance imaging (MRI) room. Where provided, an in-NICU-specific, self-shielded MRI room shall meet the following minimum requirements:

- Room size shall be a minimum of 250 square feet (23.2 square meters)
- Floor weight capacity shall be a minimum of 13,000 lbs. (5897 kilograms)

Standard 16: Administrative space
Administrative space shall be provided in the NICU for activities directly related to infant care, family support, staff supervision, or other activities routinely performed within the NICU.

Interpretation: A wide range of personnel are assigned to the NICU, many of whom require office or administrative space. When planning the NICU, administrative space should be considered for each discipline that provides service to the unit on a daily basis and needs a distinct area for carrying out their responsibilities, even if that individual has additional office space elsewhere.

Standard 17: Family support space
Space shall be provided in or immediately adjacent to the NICU for the following functions: family lounge area, lockable storage, telephone(s), and toilet facilities. Separate, dedicated rooms shall also be provided for lactation support and consultation in or immediately adjacent to the NICU. A family library or education area shall be provided within the hospital. Access to the Internet and educational materials shall be provided via a computer station in the family lounge or at the infant's bedside.

Interpretation:

Family lounge area: This should include comfortable and moveable seating and tables, as well as a play area stocked with entertainment materials for children. A nourishment area should also be considered. External windows or skylights are desirable whenever possible.

Lockable storage: Secure storage for personal items should be provided at each infant space.

Lactation support: Comfortable seating, a handwashing sink, and a means of communication with the NICU should be provided.

Family education area: This should include publications, audio-visual resources, and Internet access so that families can learn about health conditions, child development, parenting issues, and parent-to-parent support. This area might also include space and supplies to learn about and practice caregiving techniques.

Standard 18: Family transition room(s)
Family Transition room(s) shall be provided within or immediately adjacent to the NICU that allow(s) families and infants extended private time together if this function is not achieved through the availability of appropriately outfitted single-family or couplet care rooms, in order to prepare for the transition from hospital to home.

The room(s) shall have direct, private access to sink, toilet, and shower facilities, emergency call and telephone or intercom linkage with the NICU staff, sleeping facilities for two parents, and sufficient space for the infant's bed and equipment. Each room shall also have at least four electrical outlets for the use and charging of the family's electronic devices.

The room(s) can be used for other family support, educational, counseling, or demonstration purposes when unoccupied.

Interpretation: Access to a family transition room helps families prepare for discharge by acting as an intermediate space between the highly medicalized environment of the NICU and the home. The room(s) should be sufficiently equipped and sized to accommodate the parents and baby, with additional space for a physician, nurse, social worker, chaplain, or other individuals who may need to meet with the parents and baby in private.

For security reasons, transition room(s) should be situated within an area of controlled public access.

The number of electrical, medical gas, and suction outlets specified will be dependent on the function(s) intended for this area.

Sufficient family transition rooms should be provided to allow those families who wish to room in with their infants the opportunity to do so prior to discharge. The appropriate number of rooms will depend on each hospital's practice pattern, the number of single infant rooms with parent sleeping facilities, the availability of other rooms nearby, the size of the region served, and other variables.

Standard 19: Ceiling finishes

Ceilings shall be easily cleanable and constructed in a manner to prohibit the passage of particles from the cavity above the ceiling plane into the clinical environment.

The ceiling construction in infant rooms and adult sleep areas and the spaces opening onto them shall not be friable and shall have an average noise reduction coefficient (NRC) of 0.85 and a ceiling attenuation class (CAC) minimum of 29 [3].

Interpretation: In the NICU, because ceilings provide the largest area for absorbing sound, acoustic tiles as a ceiling finish material can contribute to the quality of the sound environment. To have a significant effect, an NRC of 0.90 for at least 80% of the surface area or an NRC of 0.85 for 100% of the surface is required along with a CAC minimum of 29 as a barrier to airborne sound transmission. As sound abatement is a high priority in the NICU, acoustical ceiling systems are desirable, but must be selected and designed carefully to meet this standard.

Volatile organic compounds (VOCs) and persistent bioaccumulative toxic substances (PBTs) such as cadmium are often found in paints and ceiling tiles and should be avoided. Specify low- or no-VOC paints and coatings.

Standard 20: Wall surfaces

Wall surfaces and surface-applied wall protection shall be durable and easy to clean. Wall protection shall be provided at points where contact with movable equipment is likely to occur. Sound abatement strategies shall be utilized to minimize ambient sound levels.

Color choices shall reflect local culture and climate and be modifiable (through colored light and accessory options), when possible.

Interpretation: As part of a comprehensive strategy to provide a safe and comfortable NICU environment, the ease of cleaning, durability, and acoustical properties of wall surfaces should be considered. Strategies for sound abatement may include durable high-performance acoustic wall panels that, based on installation, meet an NRC rating from 0.70 to 0.90. Sound-absorbing acoustic panels can help reduce general noise, clarify speech, and limit reverberation within enclosed areas.

The comprehensive design of the room should consider the flooring, wall finish material, and acoustic ceiling, not as separate components, but as a system to achieve the desirable ambient sound level.

Although commonly used, some vinyl wall coverings contain polyvinyl chloride and may contribute to the degradation of indoor air quality, and thus should be avoided; however new technology has produced products that emit lower levels of VOCs and have removed concerning chemicals such as phthalates, heavy metals, and formaldehyde.

Selections of products and finishes should seek to eliminate or minimize VOCs and PBTs known to be harmful to human health, such as cadmium, which is often found in paints, wall coverings, acoustical wall panels, and wood paneling systems. The design strategy should focus on the specification of low- or no-VOC paints and coatings and other building finish materials.

Color preference is impacted by culture, climate, and length of stay in a space. Ideally, some elements of the built environment are chromatically interchangeable and can be modified by the families and staff.

Standard 21: Floor surfaces

Floor surfaces shall be durable enough to withstand frequent cleaning and heavy foot and equipment traffic. Floor surfaces shall be easy to clean and maintain to minimize the ability to harbor bacterial pathogens.

Flooring material shall have a light reflectance value not to exceed 30% [9].

Flooring in infant care spaces and hallways and rooms opening onto them shall be designed for impact sound reduction [10].

Interpretation: Appropriate specifications of flooring surfaces assure that materials are durable, cleanable, easy to disinfect, attractive, comfortable, minimize unwanted noise, and address safety concerns.

Materials suitable to the standard for floor surface criteria may include resilient sheet flooring (rubber, vinyl, or linoleum) with heat- or chemically-welded seams and carpet tile with an impermeable backing. Some flooring materials may have antimicrobial and antistatic properties. Carpet tile has been shown to be an acceptable floor covering in the hospital [11] and the NICU [12] and has esthetic, comfort, and noise reduction appeal, but it is not suitable in all areas (e.g., around sinks or in isolation or soiled utility/holding areas). Small floor tiles (e.g., 12-inch squares) have many seams and may have areas of non-adherence to the subfloor. Monolithic or similar transitions that do not obstruct mobility should be provided where material changes are occurring to minimize noise and jarring of equipment. Opportunistic collection of fluid and particulates should be minimized to reduce potential sources of bacterial and fungal growth. Seams may be minimized by using sheet goods or large tile products. Any resilient sheet flooring should be selected to minimize shrinkage to reduce the risk of harboring microorganisms.

Although ease of cleaning and durability of NICU surfaces are of primary importance, consideration should also be given to indirect (reflective) glare, acoustic properties, and underfoot comfort, all factors contributing to safety for healthcare staff and patients Minimizing indirect glare will reduce discomfort and fatigue. Acoustic properties and material characteristics will directly affect noise and comfort. Reducing impact noise may be achieved with cushioning material between the surface and backing; the thicker the layer of cushion material the less the impact noise, although the flooring material's durability may be compromised. In addition to impact noise reduction, cushioning material may reduce lower extremity pressure for those who stand for long periods of time.

The selection of flooring materials is one component of a comprehensive strategy to reduce risk and increase safety in the NICU environment. Materials should be selected to minimize

chemical exposures to healthcare staff and patients. Long-term exposure to chemicals in cleaning and disinfecting products presents exposure risks that may lead to health effects. Additional efforts should be made to exclude PBTs such as polyvinyl chloride (PVC) from healthcare environments. PVC or vinyl is a common chemical found in some flooring materials, including sheet goods, tiles, and carpets. The production of PVC generates dioxin, a potent carcinogen and fumes emitted from vinyl degrade indoor air quality. Dioxin release is not associated with materials such as polyolefin, rubber (latex), or linoleum.

VOCs such as formaldehyde and chlorinated compounds such as neoprene should also be avoided when selecting adhesives or sealants for floor coverings. Specify low or no-VOC and non-toxic and non-carcinogenic materials.

Flooring-containing natural rubber (latex) should be certified non-allergenic by the manufacturer.

Every effort to minimize infant exposure to new materials off-gassing should be made. Off-gassing of new synthetic products happens over time, but initial off-gassing is significantly higher than continuous off-gassing. Infants should not be moved into an area of newly installed flooring that has not been pre-conditioned for off-gassing for a minimum of 2 weeks to permit reasonable off-gassing of adhesives and flooring materials.

Consider selecting materials that are resistant to degradation by ultraviolet light, bleach, hydrogen peroxide, and other exposure elements.

Standard 22: Furnishings

Built-in and free-standing furnishings such as cabinets and carts, especially those in the infant care areas, shall be easily cleanable with the fewest possible seams in the integral construction. Exposed surface seams shall be sealed. Furnishings shall be of durable construction to withstand impact by movable equipment without significant damage.

Interpretation: Countertops should have the fewest possible seams. Edges exposed to impact should be rounded (i.e., bull-nosed). Corners created at wall or backsplash intersections should be coved. Intersections with sinks or other devices should be sealed or made integral with the top. Casework construction should not chip or flake when struck by objects in the normal routine of infant care and should be of sufficient moisture resistance to prevent deterioration.

Furnishings in the NICU are often composite pieces, made of various parts and layers of materials that are assembled with glue or adhesives. Materials and substances typically used in these furnishings often contain VOCs such as formaldehyde, which is frequently found in pressed wood products including plywood and particle board. Vinyl-based laminates, which often are applied to the surface of pressed wood products, also contain VOCs such as PVC. Specify low- or no-VOC materials, including urea-formaldehyde-free adhesives, for all furnishings in the NICU.

Consider selecting materials that are resistant to degradation by ultraviolet light, bleach, hydrogen peroxide, and other exposure elements.

Standard 23: Ambient lighting in infant care areas

Ambient lighting levels in infant spaces shall be adjustable through a range of at least 10 to no more than 600 lux (approximately 1 to 60-foot candles), as measured on any plane at each bedside. Both natural and electric light sources shall have controls that allow immediate darkening of any bed position sufficient for transillumination when necessary.

Accurate color rendering is essential to NICU care. Luminaires used for ambient lighting shall conform to recommended fidelity (Rf) and color saturation (Rg) values as published for Medical Facilities by the Unified Facilities Criteria UFC 4–510–01 [13]. The optical reflectors in the luminaires (light fixture) shall have a neutral finish so that the color rendering properties of the light source are maintained. The sources shall avoid unnecessary ultraviolet or infrared radiation by the use of appropriate lamps, lenses, or filters [9]. Flicker index (FI) values for luminaires used for ambient lighting shall not exceed 0.1 [14]. Lighting fixtures shall be easily cleaned.

No direct view of the electric light source or sun shall be permitted in the infant space as described in Standard 6: this does not exclude direct procedure lighting, as described in Standard 24. Any lighting used outside the infant care area shall be located so as to avoid any infant's direct line of sight to the fixture.

Interpretation: Substantial flexibility in lighting levels is required by this standard so that the disparate needs of infants at various stages of development and at various times of day can be accommodated, as well as the needs of caregivers. In very preterm infants, there has been no demonstrable benefit to exposure to light. After 28 weeks of gestation, there is some evidence that diurnally-cycled lighting has potential benefits to the infant [15]. Caregivers benefit from moderate levels of ambient light in order to perform tasks and maintain wakefulness.

Control of illumination should be accessible to staff and families, and capable of adjustment across the recommended range of lighting levels. The use of multiple light switches to allow different levels of illumination is one method helpful in this regard but can pose serious difficulties when rapid darkening of the room is required to permit transillumination, so a master switch should also be provided.

Standard 24: Procedure lighting in infant care areas

Separate procedure lighting shall be mounted at each infant bed. The luminaire shall be capable of providing no less than 2000 lux at the plane of the infant bed and must be framed so that no more than 2% of the light output of the luminaire extends beyond its illumination field. This lighting shall be adjustable so that lighting at less than maximal levels can be provided.

Interpretation: Temporary increases in illumination necessary to evaluate a baby or to perform a procedure should be possible without increasing lighting levels for other babies in the same room.

Since intense light may be unpleasant and harmful to the developing retina, every effort should be made to prevent direct light from reaching the infant's eyes. Procedure lights with adjustable intensity, field size, and direction will help protect the infant's eyes from direct exposure and provide the best visual support to staff.

It is preferable that the procedure light be mounted on the headwall, ceiling, or incubator in lieu of a floor stand. This will maximize the space around the infant work area and minimize trip hazards.

Standard 25: Illumination of support areas

Illumination of support areas within the NICU, including the charting areas, medication preparation area, reception desk, and handwashing areas, shall conform to IES specifications [9].

Interpretation: Illumination should be adequate in areas of the NICU where staff perform important or critical tasks; the IES specifications in these areas are similar to but somewhat more specific than the general guidelines recommended by AAP/ACOG [2].

In locations where these functions overlap with infant care areas (e.g., close proximity of the staff charting area to infant beds), the design should nevertheless permit separate light sources with independent controls so the very different needs of sleeping infants and working staff can be accommodated to the greatest possible extent. Care must be taken, however, to ensure that bright light from these locations does not reach the infants' eyes.

Standard 26: Daylighting
At least one source of natural daylight shall be visible from all infant care areas, either from the infant care station itself or from an adjacent area. Where a window or skylight is provided, the following requirements shall be met:

- Exterior windows in infant areas or infant rooms shall be glazed with a maximum U value of 0.50.
- Exterior windows in infant areas or infant rooms shall be situated at least two feet (0.6 meters) from the infant bed. All daylighting sources shall be equipped with shading devices.

Interpretation: Windows and daylight provide important psychological benefits to staff and families in the NICU and therefore should be provided in as many spaces that adults will occupy as possible. Exposure to daylight has a substantial impact on mood and circadian health. Lack of exposure to daylight has been associated with a disruption in circadian rhythms and a decrease in the quality of sleep. While there is less data on daylight for post-partum recovery, current evidence would indicate that the benefits would be similar for stressed or post-partum families. Indoor spaces with daylight exposure have also been shown to have fewer bacteria as compared with spaces without any daylight exposure. The presence of windows and daylight is to support families and staff rather than infants since exterior windows have not been shown to enhance infant development.

Where exterior windows are provided, they should be carefully placed to prevent direct sunlight from striking the infant, IV fluids, or monitor screens, to allow easy cleaning, and to avoid glare and heat loss. Visible light transmittance (VLT) of windows should be greater than 40%. Shading devices should be easily controlled to allow flexibility at various times of day, and should either be contained within the window or easily cleanable.

Standard 27: Access to nature and other positive distractions
Views of nature shall be provided in the unit in at least one space that is accessible to all families and one space that is accessible to all staff. If direct physical access to the outdoors is not available, simulated access to nature shall be provided in at least one space that is accessible to all families and one space that is accessible to all staff. Other forms of positive distraction shall be provided for families in infant and family spaces, and for staff in staff spaces.

The provision of views via windows shall be guided by the recommendations outlined in LEED (Leadership in Energy and Environmental Design) for Healthcare [16]; IEQ Credit 8:1 Daylight and Views, except in cases where the provision of daylight and windows interferes with the recommendations provided elsewhere in this document.

Interpretation: Culturally appropriate positive distractions provide important psychological benefits to staff and families in the NICU. Looking out a window, viewing psychologically supportive art, or taking a stroll in a garden may help to reduce stress or increase productivity. When possible, windows should have views of natural environments. These environments might consist of trees, plants, human and animal activity, gardens, and landscapes. In urban settings, appropriate nature elements might include planters or water features. When such views are not possible, artwork with nature images or other nature simulations (e.g., video, virtual reality devices, and artificial representations) should be provided throughout the unit. Family and staff lounge spaces are ideal locations for views of nature and other positive distractions.

Provision should be made for direct access to nature and other positive distractions within the hospital complex. These nature environments may consist of outdoor spaces such as gardens or walking paths or indoor spaces such as greenhouses and atria.

Amenities within the natural environment might include water features, plant and animal life, and solitary and group seating. Other positive distractions might include fitness centers and access to music.

Standard 28: Acoustic environment
Infant rooms (including airborne infection isolation rooms) and adult sleep rooms, as well as the hallways or other areas in open communication with them, shall be designed to mitigate a combination of continuous background sound and operational sound of at least L_{50} of 45 dBA-weighted, slow response and an L_{10} of 65 dBA-weighted, slow response, as measured three feet from any infant bed or other relevant listener position.

Staff work, lounge, meeting rooms, family lounge, and gathering areas, as well as the hallways or other areas in open communication with them, shall be designed to mitigate the combination of continuous background sound and operational sound of at least an L_{50} of 50 dBA-weighted, slow response, and an L_{10} of 70 dBA-weighted, slow response, as measured 3 feet from any relevant listener position.

To achieve the required sound levels in infant and adult sleep rooms, building mechanical systems and permanent equipment in the room shall conform to noise criteria (NC—25 based on the manufacturer's noise ratings with allowance for other sound sources and adjustment for room loss of less than 10 dB [17]. Areas in open communication with infant rooms and adult sleep rooms shall conform to NC-30. Building mechanical systems and permanent equipment in other spaces specified in the Standard shall conform to NC-35. Building mechanical systems include heating, ventilation, and air-conditioning systems as well as plumbing, electrical, and vacuum tube systems and door mechanisms. The room or area shall meet design criteria when permanent equipment usually in the area is in operation; permanent equipment includes refrigerators, freezers, ice machines, storage/supply units, and other large non-medical equipment that is rarely replaced.

If a refrigerator or freezer is located in the infant room or a hallway in open communication with it, the condenser and fan noise shall not exceed 40 dBA.

Where personal address speakers are located in sensitive areas, announcing systems shall have adjustable volume controls for the speakers in each room and for each microphone that sends signals through the system.

Traffic unrelated to a particular patient's care, adult sleep rooms, and rooms for activities that require close attention to detail shall be routed outside these areas.

Speech privacy and freedom from intrusive sounds shall be provided by acoustic seals for doors, room-room, and hallway-room windows and by selecting materials and room components that meet design sound transmission class (STC) criteria and noise reduction criteria (NRC) given below for demising partitions in infant rooms, adult sleep rooms, family transition rooms, and conference rooms or offices in which sensitive staff and family information is discussed. All other penetrations for conduits, inset boxes, pipes, ducts, and other elements in demising partitions shall be sealed airtight to prevent noise flanking (leakage) through gaps and openings.

Fire alarms and occupant notification appliances shall be in accordance with the NFPA 101 Life Safety Code and the building code as required. At a minimum, fire alarm occupant notification systems in the NICU shall be designed using the private operating mode as permitted and described in NFPA 72, National Fire Alarm and Signaling Code. Only the attendants and other personnel required to evacuate occupants from the NICU shall be required to be notified. Only visible alarm-indicating appliances shall be permitted to be used in all infant critical care areas.

Interpretation: These criteria are more likely to be achieved with the active participation of an acoustical engineer throughout the programming, design, construction, and validation phases of the project.

The acoustic environment is a function of both the facility (e.g., building mechanical systems and permanent equipment, intrusion of exterior sounds, sound containment afforded by doors, windows, and walls, and sound-absorbing surface finishes) and its operations (e.g., human activity and the function of medical equipment and furnishings). Control of intrusive noise and a lower noise baseline (a.k.a. noise floor) can support autonomic, motor, and behavioral state stability for infants [18]. These measures can also help protect staff from the deleterious effects of workplace noise and support attention and precision in communication and task performance by lessening the noise-related risks of masking, distraction, and error [19].

The acoustic conditions of the NICU should favor speech intelligibility, normal or relaxed vocal effort, speech privacy for staff and parents, and freedom from acoustic distraction for infants and adults. Such favorable conditions encompass more than the absence of noise and require specific planning for their achievement. Speech Intelligibility ratings in infant areas, parent areas, staff work areas, and areas of sensitive staff and family communication should be "good" to "excellent" as defined by the International Organization for Standardization ISO 9921:2003. Speech intelligibility for non-native but fluent speakers and listeners of a second language requires a 4–5 dBA improvement in signal-to-noise ratio (the difference between speech and background levels) for similar intelligibility with native speakers.

Air handling and mechanical equipment noise typically determines background noise levels. The use of flexible ducts listed and labeled to the UL 181 Standard for Factory-Made Air Ducts and Air Connectors and Class 0 or Class 1 can help lower the noise at the supply air outlets. Duct lining should conform to ASHRAE 170 Ventilation of Health Care Facilities.

Acoustically absorptive surface materials on multiple surfaces can help provide effective noise control. The ceiling has the largest surface area available for sound-absorbing materials. Flooring materials absorb only a small amount of high-frequency sound but can limit sound production from striking—e.g., footfall, and dragging equipment. Vibration isolation pads or specialty spring assemblies are recommended under leveling feet of permanent equipment and appliances in noise-sensitive areas or areas in open or frequent communication with them.

Telephones audible from the infant area should have adjustable announcing signals.

Water supply materials and faucets in infant areas and adult sleep rooms be selected to minimize on/off noise, and should provide instant warm water in order to minimize time "on".

Many incompatible adjacencies are possible in the NICU—for example, a break area, meeting room, or mechanical room sharing a wall with an infant room or adult sleep room. The transmission loss or attenuation criteria below apply to horizontal barriers (for example, walls, doors, windows) and vertical barriers (for example, between floors). The sound transmission coefficient (STC) rating spans speech frequencies and is relevant for the separation of spaces with conversational and other occupant-generated noise.

Recommended STC and NRC ratings	
Infant and adult sleep rooms	STC-50
Procedure rooms	STC-50
Consultation rooms	STC-55
Conference rooms	STC-50
Pedestrian-only corridor	STC-45
Equipment corridor	STC-55
Reception	STC-50
Meeting room with amplified sound	STC-60
Staff work area	STC-50
Administrative Office	STC-45
Mechanical area	NRC 60–65
Electrical area	NRC 50–55

Table a. continued

Post-occupancy validation should include noise and vibration measurement, reporting, and remediation. Measurement of NC levels should be made at the location of the infant or adult bed or at the anticipated level of the adult head in other areas. Each bed space must conform to the Standard.

Standard 29: Usability testing

Each new NICU shall perform usability testing (e.g., simulation-based mock-up evaluations) during project design and commissioning. Involving multidisciplinary teams that include family members will enhance physical design, process resiliency, and patient safety.

Interpretation: Latent safety threats (LSTs) emerge when existing processes are translated to the new environment. Simulation-based testing and mock-up evaluations help identify LSTs, improve planned NICU design and process, and prepare staff. Evaluations during the design process differ from those during post-construction commissioning. Pre-construction design-focused evaluations use physical or virtual reality mock-ups to help guide design decisions that optimize the built environment for safe and efficient patient- and family-centered care. Commissioning evaluations just prior to move-in gives greater clarity about LSTs at the interface between clinical teams and new technology infrastructure. Though facility redesign is not feasible during commissioning evaluations, identification of LSTs enables mitigation prior to exposing babies through training or workflow modification.

Multidisciplinary team participation that includes family members in simulation-based scenarios may reveal unexpected consequences of performing routine and emergent workflows in the new environment. Including family members representing the diversity served by the NICU in simulations is crucial to enhance outcomes. Diverse family collaborators provide valuable perspectives during simulations and debriefing. Consideration should be given to ensure that family members are selected and supported in participating to minimize any repeat trauma or undue burden (e.g., PTSD) from participation in the scenario enactments or process. Family members with experience serving as a member of a family advisory council and/or a design planning committee may be particularly helpful to this process and can provide richly informative staff-family interaction insights.

Mock-ups range from simple (e.g., tape on the floor) to detailed (e.g., plywood-constructed walls and furnishings) to virtual reality representations of the planned space. Virtual reality mock-ups are 3D, fully immersive, photorealistic, interactive virtual environments that are experienced using a head-mounted display. A favorable return on investment has been estimated for evaluations within each mock-up type (simple, detailed, and virtual reality), ranging from $5.06 to $26.85 for every dollar invested [20].

A framework describing how to plan, design, and evaluate a mock-up, along with resources and templates, is publicly available through the Health Quality Council of Alberta at www.hqca.ca/humanfactors. The framework and the guiding principles from the framework have been incorporated into the National Standards of Canada (CSA Z8000-18) and are promoted as an FGI-supported

resource on the FGI website. The following principles build on those found in the framework:

1. Simulation-based mock-up evaluations should be considered for each design phase from schematic design through commissioning. The consideration should occur during the pre-design stage.
2. Each mock-up evaluation should be thoroughly planned. The scope of evaluations should be outlined in the pre-design stage with attention to the time and costs required to build the necessary fidelity for that stage. Define a timeline incorporating each evaluation phase, the staff education plan, construction contingencies, and the projected move-in day. Gather stakeholder commitment around the timeline. Delineate clear evaluation objectives for each design phase to maximize effectiveness. Evaluation objectives might include unit configuration, room size and configuration, space and access requirements, visibility requirements, lighting requirements, and/or ceiling and floor color choices. Solicit multidisciplinary input to generate robust evaluation objectives that not only structure each evaluation but also pay dividends in participant engagement as well as in LST reveals.
3. Building of the mock-up should align with evaluation timing and objectives. The degree to which a mock-up is completed (mock-up fidelity) can vary significantly. The mock-up should be built to an appropriate level of fidelity to enable testing of evaluation objectives during the appropriate design phase and may, for example, include real or mock-up furniture and equipment, tape-out walls and equipment, or fully constructed walls with a ceiling and functioning lights.
4. Roles and responsibilities for those involved in the evaluation should be clearly defined. This includes identifying who will be responsible for evaluation design, staging the mock-up, data collection, and data analysis as well as who will participate in the simulation-based scenario enactments. Areas of specific expertize (e.g., human factors) should be assessed to identify if individuals external to the organization are needed.
5. The simulation scenarios that are created and enacted should test evaluation objectives. Frequent, urgent, or challenging clinical situations will prompt a series of simulation tasks that draw participants toward these objectives. The mock-up space, supplies, and equipment help immerse participants in the simulation. The scenarios are enacted by users of the space within the mock-up, which includes needed supplies and equipment (real or mock-ups).
6. Recommendations will be evidence-based as observed during simulation-based scenario enactments. Data collected through debriefings and video analysis identify potential issues and successes with the planned design. Identified issues should be assigned to process workgroups for correction, tracked for resolution, and disseminated to staff. Staff awareness can be enhanced through regular messaging or other simulation-based activities.

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DISCLAIMER

The acoustic terms defined in the Glossary are defined in conceptually although not technically accurate language. Technically precise definitions can be found in official documents and professional textbooks.

COMPETING INTERESTS

The authors declare no competing interests.

GLOSSARY

Adult sleep areas	Rooms designated for parent or staff sleep or rest.
Ambient lighting	The continuous "background" illumination for a specified area.
Ambient temperature	Thermal measurement of the generalized space around the neonate. Usually refers to room temperature.
Backsplash	A vertical, protective surface located behind a sink or counter.
Biohazardous	Refers to human tissue, cells, body fluids, or culture materials that may contain infectious or other hazardous materials.
Cabinetry	Box-like furniture constructed for storage; could consist of drawers, counters, or shelves.
Casework	The components that make up a cabinet.

Clear floor space	The space available for functional use excludes other defined spaces (e.g., plumbing fixtures, anterooms, vestibules, toilet rooms, closets, lockers, wardrobes, fixed-based cabinets, and wall-hung counters).
Cubicle	Space enclosed on multiple sides with full height or partial partitions with at least one opening without a door.
External windows	Windows are located on the exterior skin of a building, looking outside the building or into courtyards.
Flicker	A relative measure of the cyclic variation in output of a light source (percent modulation). It is given by the expression $100\% \times [(A - B)/(A + B)]$ where A is the maximum and B is the minimum output during a single cycle.
Hands-free handwashing station	An area that provides a free-standing sink, meets all handwashing station requirements described in Standard 10, such as space for cleaning agents and drying capability, and in addition, is operable without the use of hands.
Infant bed	Furniture or equipment used to hold an infant.
Infant room	Contains the infant space.
Infant space	The area surrounding the infant bed contains all support equipment and furniture.
Luminaire	A complete lighting unit consisting of a lamp or lamps and the parts designed to distribute the light, to position and protect the lamp(s), and to connect the lamp(s) to the power supply. (Also referred to as fixture.)
Noise	Noise is unwanted, interfering, and/or harmful sound.
Non-public service corridors	Designated traffic pathways that are restricted to staff use for staff access and patient or material transport.
Parent–infant rooms	Separate rooms in or adjacent to the NICU are designed for parents to room in with their infants during some portion of the NICU stay. These rooms include infant care space, parent sleeping space, and facilities as described in Standard 16.
Persistent bioaccumulative toxins	Persistent bioaccumulative toxins (PBTs) are substances that transfer easily among air, water, and land and are stored in fatty tissue. As a consequence, they accumulate or magnify in the food chain, and also span generations. Effects on human health range from eye, nose, and throat irritation to organ and nervous system damage to cancer.
Positive distractions	Sensory experiences which enable an individual to focus on psychologically supportive and compelling stimuli. These stimuli are intended to divert attention from negative experiences. Positive distractions should be culturally- and age-appropriate and could range from nature and art to video games and music.
Room	Space enclosed with full-height partitions or walls equipped with a door.
Single-family rooms	Rooms within the NICU are analogous to private patient rooms elsewhere in the hospital that are designed to provide for the care of one or more infants from a single family. These rooms have the usual provisions for infant care as well as space for family members to stay at the bedside or in the room for extended periods of time. A sleeping area for family members is often provided within these rooms, but may also be situated immediately adjacent to them, or elsewhere in the NICU or hospital.
Volatile organic compounds	Volatile organic compounds (VOCs) are the primary source of indoor air pollution and are measured as organic gases. VOCs such as formaldehyde and urethane are released from products during use and often are found in pressed wood products and household products including paint and wood preservatives. Importantly, the EPA reports that levels of VOCs average 2–5 times higher in indoor environments than outdoors. Health effects are directly related to the amount of exposure, but range from allergies to nervous system disorders to cancer.
Allowable sound level criteria, noise criteria (NC), and room criteria (RC)	Sound levels can be measured over the entire spectrum of audible frequencies. For some technical purposes (e.g., spaces in which verbal communication is important) the spectrum can be divided into smaller frequency spans, such as octaves or specific narrow bandwidths. Background noise within a room is often measured in octave bands for comparison with a family of smooth, balanced curves, called noise criteria (NC) or room criteria (RC). This criteria system is used for the design and validation of building spaces because it is more descriptive than a single number such as dB or dBA, which does not carry enough information to distinguish between a pure tone, a balanced spectrum, or a sound dominated by lower or higher frequencies.
Areas in open acoustic communication	Areas without a barrier wall or an operable door between them or areas separated by a door that is intended to remain open most of the time.
Background or facility noise	Background or facility noise: Background noise refers to the continuous ambient sound in space due to the mechanical and electrical systems of the facility or building itself and to permanent equipment. Background noise is produced by sources outside the building and by the building's own heating, ventilation, and air-conditioning systems, vacuum tube systems, elevators, plumbing, automatic doors, etc. Because occupant-generated noise will add to the "noise floor" or background noise of the building, allowable background level criteria are set low enough to prevent annoyance, reduced speech intelligibility, sleep disturbance, or other disturbances after the building is occupied.
CAC (ceiling articulation class)	Rates a ceiling's efficiency as a barrier to airborne sound transmission between adjacent closed offices [rooms]. Shown as a minimum value, previously expressed as CSTC (ceiling sound transmission class). A single-figure rating derived from the normalized ceiling attenuation values in accordance with classification ASTM E413, except that the resultant rating shall be a designated ceiling attenuation class. (Defined in ASTM E 1414). An acoustical unit with a high CAC may have allowed NRC. (cited from www.armstrong.com).
Ceiling plenum	The area between the finished ceiling and the underside of the structure above, often used for ductwork, electrical wiring, plumbing pipes, etc. as well as for recessed ceiling lights.
Demising partitions	A "demising" assembly, partition, floor, ceiling, etc. is one that separates the space of one occupant or department from that of another, or from a corridor. Partitions within an occupant or department space are non-demising partitions. For example, the wall between two patient rooms is demising, but the partition within a patient room that encloses the bathroom for that room is non-demising. Likewise, the wall between one office suite and another is a demising wall, but the walls within the suite itself are non-demising. The wall between a mechanical or electrical equipment room and any occupied space is a demising wall. In a residential apartment building, the partition between the two units is demising, but the partitions between rooms within the same apartment are not demising.
Facility vs. operational noise	Exterior sources (e.g., street traffic and outdoor building mechanical equipment) and interior sources (e.g., air conditioning and exhaust systems) generate facility noise. It exists in the empty building as it is constructed. The people and equipment that occupy the building generate operational noise.
Operational noise	Operational noise is generated by people and equipment that occupy the building and are separable from the building. A general rule of thumb states that occupants and their equipment will add about 10 dBA to background noise. However, this generalization does not apply to all room uses. For example, two or three people in an office environment with a 45–55 dBA background might add about 10 dBA, but the same group in a quiet conference room with a 35–45 dBA background might add 20 dBA. A large group of people might add 40 dBA. In intensive care units with hard surfaces, close spacing of patient beds, and large amounts of staff and equipment the occupied room noise may be 20 dBA or more above the background with brief excursions well above that.
Occupant-produced noise	Occupant noise is not under the control of architects and engineers but can be incorporated as a design parameter through the use of a matching architectural requirement

	(e.g., wall and ceiling absorption criteria). Control of occupant-produced noise lies primarily in the realm of quality assurance programs and hospital management.
Permanent equipment	Large equipment that is necessary for essential functions of the NICU and that is rarely replaced. Such equipment includes refrigerators, freezers, ice machines, and mechanical/electrical storage systems for supplies and medication. Permanent equipment is distinct from medical equipment used for direct patient care.
Reflective and absorptive surfaces: Noise reduction coefficient (NRC)	Within any closed space, sound levels are affected by reflections of soundwaves from surfaces. When the surfaces are predominantly hard, sound pressure builds up in the space, increasing the original level with reverberation. Conversely, when the surfaces are soft or acoustically absorptive, reflected energy is reduced and sound pressure does not build up. Acoustically absorptive surface materials are rated by a noise reduction coefficient (NRC), which is an average of absorption coefficients in the middle range of the audible spectrum of sound frequencies. Although an oversimplification, the NRC rating of a material can be thought of as the percentage of sound energy absorbed. If the NRC of a wall panel, for example, is 0.65, about 65% of the sound energy of a source is absorbed and about 35% reflected back into the room.
Speech privacy	"Methods used to render speech unintelligible to the casual listener." This definition embodies two key concepts: (a) the measurement of intelligibility/unintelligibility, which is a practice familiar to five generations of acoustics professionals since the first work done on the Articulation Index in the 1940's by Leo Beranek and others; and (b) the viewpoint of the "casual listener." That is, this definition of speech privacy does not cover intentional or assisted listening (quoted from the webpage of the American National Standards Institute (ANSI), and the Glossary of American National Standard T.1–523–2001, a standard maintained by the U.S. Department of Commerce, National Telecommunications and Information Administration, Information Security program (INFOSEC).)
Vibration	Vibration is perceptible to humans at a certain magnitude or level and can cause discomfort or annoyance. Larger magnitudes of vibration can cause the rattling of lightweight building elements, superficial cracking in partitions, or even structural damage. Very small magnitudes of vibration not perceptible to humans can disturb high-magnification optical microscopes or very sensitive electronic equipment. Sources of vibration common in hospitals are helicopter flyovers and landings/take-offs, magnetic resonance imagers, sound systems, and heavy trucks. Buildings can be constructed to prevent the propagation of vibration through the building.

ADDITIONAL INFORMATION

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