JOINT CANADA – UNITED STATES NATIONAL STANDARD

ANSI/CAN/UL 3300:2024

STANDARD FOR SAFETY

Service, Communication, Information, Education and Entertainment Robots – SCIEE Robots

Approved American National Standard

ANSI

ANSI/UL 3300-2024

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SCC FOREWORD

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UL Standard for Safety for Service, Communication, Information, Education and Entertainment Robots – SCIEE Robots, ANSI/CAN/UL 3300

First Edition, Dated May 14, 2024

Summary of Topics

The First Edition of ANSI/CAN/UL 3300, Standard for Service, Communication, Information, Education and Entertainment Robots – SCIEE Robots, dated May 14, 2024.

The new requirements are substantially in accordance with Proposal(s) on this subject dated December 1, 2023 and March 15, 2024.

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ANSI/CAN/UL 3300:2024

Standard for Service, Communication, Information, Education and Entertainment Robots – SCIEE Robots

First Edition

May 14, 2024

This ANSI/CAN/UL Safety Standard consists of the First Edition.

The most recent designation of ANSI/UL 3300 as an American National Standard (ANSI) occurred on May 14, 2024. ANSI approval for a standard does not include the Cover Page, Transmittal Pages, Title Page, Preface or SCC Foreword.

This Standard has been designated as a National Standard of Canada (NSC) on May 14, 2024.

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Preface

This is the First Edition of ANSI/CAN/UL 3300, Standard for Service, Communication, Information, Education and Entertainment Robots – SCIEE Robots.

ULSE is accredited by the American National Standards Institute (ANSI) and the Standards Council of Canada (SCC) as a Standards Development Organization (SDO).

This Standard has been developed in compliance with the requirements of ANSI and SCC for accreditation of a Standards Development Organization.

This ANSI/CAN/UL 3300 Standard is under continuous maintenance, whereby each revision is approved in compliance with the requirements of ANSI and SCC for accreditation of a Standards Development Organization. In the event that no revisions are issued for a period of four years from the date of publication, action to revise, reaffirm, or withdraw the standard shall be initiated.

Annex A, Annex B, Annex C, and Annex F, identified as Normative, form mandatory parts of this Standard.

Annex D and Annex E, identified as Informative, are for information purposes only.

In Canada, there are two official languages, English and French. All safety warnings must be in French and English. Attention is drawn to the possibility that some Canadian authorities may require additional markings and/or installation instructions to be in both official languages.

This joint American National Standard and National Standard of Canada is based on, and now supersedes, the Third Issue of the Outline of Investigation of UL 3300.

Comments or proposals for revisions on any part of the Standard may be submitted at any time. Proposals should be submitted via a Proposal Request in the Collaborative Standards Development System (CSDS) at https://csds.ul.com.

This Edition of the Standard has been formally approved by the Technical Committee (TC) on Service, Communication, Information, Entertainment And Education Robots, General Requirements, TC 3300.

This list represents the TC 3300 membership when the final text in this Standard was balloted. Since that time, changes in the membership may have occurred.

TC 3300 Membership

Name	Representing	Interest Category	Region
Arab, Aliasghar	Agile Safe Autonomy by Narranj LLC	Testing & Standards Org.	USA
Callahan, Haley	UL Standards & Engagement	TC Project Manager (Non-Voting)	USA
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TC 3300 Membership Continued

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This Standard is intended to be used for conformity assessment.

The intended primary application of this Standard is stated in its scope. It is important to note that it remains the responsibility of the user of the standard to judge its suitability for this particular application.

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1 Scope

This document establishes the safety requirements for Service, Communication, Information, Education and Entertainment (SCIEE) robots.

These requirements supplement the safety requirements for the intended, non-robotic function as described in the relevant identified standards CSA C22.2 No. 62368-1/UL 62368-1, Audio/Video, Information and Communication Technology Equipment; or CSA C22.2 No. 60335-1/UL 60335-1, Household and Similar Electrical Appliances, including the applicable Part 2. Mobility and/or uncontained manipulation introduce potential for hazard due to the speed and mass of the robot, use environment and other considerations described herein. Where applicable, these requirements cover robotics intended for use in indoor and outdoor locations.

The scope includes SCIEE robots intended for use by, or in close proximity to, the general consumer.

These requirements do not apply to:

– On- or off-road transport of persons;

– Use in industrial environments, including training simulators for industrial applications;

– Use in hazardous locations;

– Use as personnel protective equipment;

– Agricultural use;

– Use in food preparation;

– Use to treat, alleviate instability, or move individuals in hospitals, care facilities or in the home;

– Use as medical devices or in medical environments;

– Robotic functions that have no safety dependencies (i.e., non-safety-related functions, e.g., accuracy of AI query responses, efficacy of a security alarm); or

– Robotic functions described in the relevant end-product safety standard.

Examples of such standards include:

– Commercial floor cleaning machines covered by CSA C22.2 No. 336, Particular requirements for rechargeable battery-operated commercial robotic floor treatment machines with traction drives;

– Portable battery-operated automatic vacuums covered by UL 1017, Standard for Vacuum Cleaners, Blower Cleaners, and Household Floor Finishing Machines;

– Outdoor commercial drones – UL 3030, Standard for Unmanned Aerial Vehicles; and

– Robots identified as a toy by the manufacturer and intended for play only by children covered by the Standard for Electric Toys, UL 696 and/or ASTM F963, Standard Consumer Safety Specification for Toy Safety.

NOTE The requirements of UL 3300 can be applied to robots with multiple use cases, some of which are not specifically covered.

2 Normative References

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

AATCC 20, *Test Methods for Fiber Analysis: Qualitative*

AATCC 20A, *Test Methods for Fiber Analysis: Quantitative*

ASTM F963, *Standard Consumer Safety Specification for Toy Safety*

Code of Federal Regulations, 16 CFR Part 24, *Guides for Select Leather and Imitation Leather Products*

Code of Federal Regulations, 16 CFR Part 303.15, *Required label and method of affixing*

Code of Federal Regulations, 16 CFR Part 303.4, *English language requirements*

Code of Federal Regulations, 16 CFR Part 303.43, *Fiber Content tolerances*

Code of Federal Regulations, 16 CFR Part 423, *Care Labelling of Textile Wearing Apparel and Certain Piece Goods*

Code of Federal Regulations, 16 CFR Part 1500.49, *Technical requirements for determining a sharp metal or glass edge in toys and other articles intended for use by children under 8 years of age*

Code of Federal Regulations, 16 CFR Part 1610, *Standard for the Flammability of Clothing Textiles*

Code of Federal Regulations, 167 CFR Part 205.100, *National Organic Program*

CSA C22.2 No. 94.2:20, *Enclosures for electrical equipment, environmental considerations*

CSA C22.2 No. 62368-1, *Audio/Video, information and communication technology equipment – Part 1: Safety requirements*

CSA C22.2 No. 60335-1, *Safety of household and similar appliances – Part 1: General requirements*

CSA C22.2 No. 60335-2-29, *Household and similar electrical appliances – Safety – Part 2-29: Particular requirements for battery chargers*

IEC 60068-2-6, *Environmental Testing – Part 2-6: Tests – Test Fc: Vibration (sinusoidal)*

IEC 60068-2-14, *Environmental Testing – Part 2-14: Tests – Test N: Change of Temperature*

IEC 61000-4-2, *Electromagnetic compatibility (EMC) – Part 4-2: Testing and measurement techniques – Electrostatic discharge immunity test*

IEC 61000-4-3, *Electromagnetic compatibility (EMC) – Part 4-3: Testing and measurement techniques – Radiated, radio-frequency, electromagnetic field immunity test*

IEC 61000-4-4, *Electromagnetic compatibility (EMC) – Part 4-4: Testing and measurement techniques – Electrical fast transient/burst immunity test*

IEC 61000-4-5, *Electromagnetic compatibility (EMC) – Part 4-5: Testing and measurement techniques – Surge immunity test*

IEC 61000-4-6, *Electromagnetic compatibility (EMC) – Part 4-6: Testing and measurement techniques – Immunity to conducted disturbances, induced by radio-frequency fields*

IEC 61000-4-8, *Electromagnetic compatibility (EMC) – Part 4-8: Testing and measurement techniques – Power frequency magnetic field immunity test*

IEC 61000-4-11, *Electromagnetic compatibility (EMC) – Part 4-11: Testing and measurement techniques – Voltage dips, short interruptions and voltage variations immunity tests for equipment with input current up to 16 A per phase*

IEC 61508, *Functional Safety of Electrical/Electronic/Programmable Electronic Safety-Related Systems (all parts)*

IEC 62061, *Safety of Machinery – Functional Safety Of Safety-Related Control Systems*

IEC/TS 62998-1, *Safety of Machinery – Safety-Related Sensors Used For The Protection Of Persons*

ISO 12405-4, *Electrically propelled road vehicles – Test specification for lithium-ion traction battery packs and systems – Part 4: Performance testing*

ISO 13849, *Safety of machinery – Safety-related parts of control systems (all parts)*

ISO 13850, *Safety of machinery – Emergency stop function – Principles for design*

ISO TS 15066, *Robots and Robotic devices, Collaborative Robots*

UL 50E, *Enclosures for Electrical Equipment, Environmental Considerations*

UL 62, *Flexible Cords and Cables*

UL/ULC 2271, *Batteries for Use in Light Electric Vehicle (LEV) Applications*

UL/ULC 2580, *Batteries for Use in Electric Vehicles*

UL 2595, *General Requirements for Battery-Powered Appliances*

UL 5500, *Remote Software Updates*

UL 60335-1, *Household and Similar Electrical Appliances, Part 1: General Requirements*

UL 60335-2-29, *Household and Similar Electrical Appliances – Safety – Part 2-29: Particular Requirements For Battery Chargers*

UL 60730-1, *Automatic Electrical Controls – Part 1: General Requirements*

UL 62368-1, *Audio/Video, Information and Communication Technology Equipment – Part 1: Safety Requirements*

15 USC 45, *Unfair methods of competition unlawful; prevention by Commission*

3 Terms, Definitions and Abbreviated Terms

3.1 Abbreviations

Abbreviations are summarized alphabetically in Table 1.

Table 1
Abbreviations

ODD	Operational Design Domain
OTS	Off the Shelf
PL	Performance Level
SCIEE robot	Service, Communication, Information, Education and Entertainment Robot
SIL	Safety Integrity Level

3.2 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

– IEC Electropedia: available at https://www.electropedia.org/

– ISO Online browsing platform: available at https://www.iso.org/obp

3.3 Function terms

3.3.1
collision avoidance
safety function involving non-contact sensing (e.g., lidar) plus a predetermined action (e.g., stopping, braking, decelerating) to avoid impact with a person.

3.3.2
emergency stop
safety function which is intended to avert arising or reduce existing hazards to persons, damage to machinery or to work in progress, and be initiated by a single human action.

[SOURCE: ISO 12100]

3.3.3
fail-safe routine
routine intended to bring the robot, including its manipulator(s), end-effector(s), and/or payloads into a safe, controlled state in response to a condition that could compromise safety, such as detection of a hardware fault, loss of communications with the docking station, or excessive battery discharge.

3.3.4
non-robotic function
function of a robot that consists of energy sources that can be identified as electrical, mechanical, thermal, chemical and/or radiation which are needed for the normal operation and performance of the robot.

3.3.5
protective stop
type of interruption of operation that allows a cessation of motion for safeguarding purposes and which retains the program logic to facilitate a restart.

[SOURCE: ISO 8373]

3.3.6
robotic function
a degree of autonomy that enables mobility and motion, i.e., location, manipulation, or positioning.

[SOURCE: ISO 8383, modified definition of "robot"]

3.3.7
safety function
function whose failure can result in an immediate increase of risk(s).

EXAMPLE Safety-limited speed (3.3.8) and collision avoidance (3.3.1) are examples of safety functions.

Note 1 to entry: Safety functions are defined in 8.2, Safety functions, or by manufacturer risk assessment (see 8.1, Risk assessment).

[SOURCE: ISO 12100, modified]

3.3.8
safety-limited speed
safety function that limits the speed of the robot or any of its parts.

3.4 Hazard terms

3.4.1
critical edge
a level change that the robot cannot traverse safely during one or more of its operating modes.

EXAMPLE A robot can climb stairs but must be able to detect the stairs and then transition into a different walking mode to do it safely.

3.4.2
entrapment
hazard involving a robot trapping a person in a way so they cannot free themselves, either between parts of the robot (e.g., gripper end-effector) or against another object (e.g., wall, floor).

3.4.3
horizontal impact
hazard involving part of a robot contacting a person while the robot is moving horizontally on a travel surface.

3.4.4
vertical fall
hazard involving a robot falling (e.g., due to loss of balance, critical edge) with its velocity increased past its rated speed by gravity.

3.5 General terms

3.5.1
docking station
an external accessory part of the robot to which the robot returns, or is returned by the user, to charge the robot's battery and/or communicate with a network.

Note 1 to entry: A docking station is also known as a charging station, charger and / or variations on this.

3.5.2
end-effector
device specifically designed for attachment to the manipulator to enable the robot to perform its task.

EXAMPLE Gripper

[SOURCE: ISO 8373]

3.5.3
leg (robotic)
mechanism of interconnected set of links and joints which is actuated to support and propel the mobile robot by making reciprocating motion and intermittent content with the travel surface.

[SOURCE: ISO 8373, modifed]

3.5.4
manipulator
mechanism usually consisting of a series of segments, jointed or sliding relative to one another, for the purpose of moving objects usually in several degrees of freedom.

[SOURCE: ISO 8373, modified]

3.5.5
mobility
motion that results in relocation of the robot within its use environment.

3.5.6
operational design domain (ODD)
the set of environments and use cases the robot is intended to operate within. This includes not only direct environmental conditions and geographic restrictions, but also a characterization of the set of objects, events, and other conditions that will occur within that environment.

3.5.7
outdoor location
location for robot where protection from the weather and other outdoor influences provided by a building or other structure is limited or non-existent.

3.5.8
payload
a rated physical load to be carried by a robot.

3.5.9
robot, legged
mobile robot that travels using one or more legs. See 3.5.3, leg (robotic).

[SOURCE: ISO 8373]

3.5.10
sensor unit
analog or digital device that detects the surrounding environment that produces a dynamic output for processing to represent a physical parameter or form necessary for control of the robotic function.

EXAMPLE The CCD (charge-coupled device) is the sensor unit part of a camera. The laser light and light detector together form the sensor unit of lidar.

Note 1 to entry: For passive detection, the receiver is the sensor unit; for active detection, the transmitter and receiver together are the sensor unit.

3.5.11
space
three dimensional volume.

[SOURCE: UL 1740]

3.5.12
space, maximum
space which can be swept by the moving parts of the robot as defined by the manufacturer plus the space which can be swept by the end-effector and the payload.

[SOURCE: UL 1740]

3.5.13
supervising operator
an instructed person who places a SCIEE robot into service, monitors its operation, and is capable of intervening to take control of the robotic function.

EXAMPLE Security robot monitored by local security patrol.

Note 1 to entry: An instructed person that configures and/or initiates robot use without monitoring the robot's real-time operation or without being able to intervene with the robot's operation is not considered to be a supervising operator.

3.5.14
vulnerable person
an individual at greater risk of harm from products or systems, due to age, level of literacy, physical or mental condition or limitations, or inability to access product safety information.

[SOURCE: ISO/IEC Guide 51]

4 General Requirements

Robots shall be constructed so that they function safely, causing no risk of harm to persons or surroundings, when stationary or mobile. This includes in normal use as represented by the robot specification, environmental use conditions, and reasonably foreseeable misuse. In general, this principle is fulfilled by individually considering the intended use, the energy sources, the robotic function, and any combination of the foregoing.

EXAMPLE A classroom telepresence robot (audio / video user interface) is considered the intended use. Autonomous mobility (not requiring human interaction) is considered to be the robotic function.

Requirements are specified in the relevant Clauses and, where referenced in those Clauses, in the relevant annexes.

Where compliance of materials, components or subassemblies is demonstrated by inspection, such compliance may additionally be determined by review of published data or test results.

Tests are conducted on the complete robot unless specifically stated. Where it is necessary to defeat a feature to assess a protective means, it shall be stated in the test procedure.

5 Non-robotic Function

The requirements for safeguards against classified energy sources specified in CSA C22.2 No. 62368-1/UL 62368-1 are applicable to SCIEE robots. The energy sources covered within CSA C22.2 No. 62368-1/UL 62368-1 are:

– General requirements: CSA C22.2 No. 62368-1/UL 62368-1 Clause 4;

– Electrically caused injury: CSA C22.2 No. 62368-1/UL 62368-1 Clause 5 (Risk of electric shock);

– Electrically caused fire: CSA C22.2 No. 62368-1/UL 62368-1 Clause 6 (Risk of fire);

– Injury caused by hazardous substances: CSA C22.2 No. 62368-1/UL 62368-1 Clause 7 (Chemical);

– Mechanically caused injury: CSA C22.2 No. 62368-1/UL 62368-1 Clause 8 (Mechanical sources from non-mobility, i.e., static operation), see note;

– Thermal burn injury: CSA C22.2 No. 62368-1/UL 62368-1 Clause 9; and

– Radiation: CSA C22.2 No. 62368-1/UL 62368-1 Clause 10.

NOTE 1 Mechanically caused injury based on mobility and robot motion are covered in UL 3300.

For applications within the scope of CSA C22.2 No. 60335-1/UL 60335-1 and the specific Part 2, the applicable requirements may be used as an alternative to CSA C22.2 No. 62368-1/UL 62368-1. When CSA C22.2 No. 60335-1/UL 60335-1 is selected, the additional requirements specified in Ageing test on motors are to be applied.

For robots identified for use in a home, residence or school, temporary or permanent, there is no lower or upper age limit considered for intended use. The requirements as noted below are applied.

A vulnerable person intended to use the robot can be a minimum age of 3 years; or when considered elderly, they are independent needing limited to no assistance.

NOTE 2 While many people who are aging or who have disabilities would not self-identify as "vulnerable", in the context of this Standard they can be vulnerable, insofar as they cannot clearly perceive or understand the robot or actions it can take, or the potential consequences of difficulties in perception or understanding.

Robots with intended uses in addition to SCIEE shall comply with the relevant safety standard covering that intended use. When requirements differ between the standards, the most onerous requirement(s) shall be applied.

EXAMPLE If the relevant safety standard for an application specified a pollution degree 2, and another relevant standard specifies a pollution degree 3, this robot with multiple applications would be subject to the requirements for pollution degree 3.

Compliance is determined by inspection and tests.

5.1 Requirements for components

5.1.1 General

Components used in and with the robot are to meet the component requirements specified in CSA C22.2 No. 62368-1/UL 62368-1. Where cited in this Standard, the component requirements are modified or replaced.

5.1.2 Power supplies

Power supplies shall comply with Clause 9 of this Standard, Electric Power Sources.

5.1.3 Batteries

Batteries and cells shall comply with Clause 11 of this Standard, Batteries.

5.1.4 Toxicology

The following requirements from ASTM F963 are applicable to substances and materials that make up accessible surfaces:

– Hazardous materials, and

– Heavy elements.

5.1.5 Textiles

For robots covered in whole or part by textiles, the additional requirements in Annex A, Textiles, are to be applied.

In addition to meeting the requirements in Annex A, Textiles, the textile shall also meet the requirements for Code of Federal Regulations (CFR) 16, Part 1610, as defined in ASTM F963, Flammability testing procedure for fabrics.

For robot constructions where the textile provided is not intended to be separated from the robot body, the combination of the solid substrate and textile shall be subject to the flammability test in ASTM F963, Flammability testing procedure for solids and soft toys.

5.2 Accessibility

All accessibility requirements from the non-robotic standards shall be met except where modified or replaced as cited by this Standard.

5.2.1 Test probe

The accessibility test probe in CSA C22.2 No. 62368-1/UL 62368-1, Openings tested with straight unjointed test probes, shall be used to assess access to mechanical energy sources and physical motion of the robot.

5.2.2 Size of parts

Accessible parts shall not be removable from the robot by a vulnerable person if they can fit entirely inside the small part cylinder of ASTM F963, Small parts cylinder.

Compliance is determined by inspection and review of data. When it is unclear if the construction prevents access to small parts and if data is not available, the following tests shall be conducted:

– The force test in CSA C22.2 No. 62368-1/UL 62368-1, Steady force test, 30 N;

– Torque test for removal of components, 7.2.13.1; and

– Tension test for removal of components, 7.2.13.2.

5.2.3 Environmental conditions

5.2.3.1 Outdoor locations or indoor wet locations

Robots intended for outdoor locations and/or indoor wet locations shall:

– be rated minimum 3R in accordance with CSA C22.2 No. 94.2/UL 50E or IPX4 in accordance with IEC 60529;

– not have accessible circuits or parts that exceed 15 V rms, 30 Vdc, or 21.2 Vpk; and

– comply with the Exposure to moisture test in 7.4.10.

5.2.4 Sharp edges

Robots shall not have sharp edges in any accessible areas of the completed construction. The Sharp edge test as described in 7.2.12 is to be conducted to assess access to any accessible sharp edges where the edge construction is questionable. Edges are considered potentially hazardous if they fail the sharp edge test described in Code of Federal Regulations (CFR) 16, Part 1500.49. Edges other than metal and glass are defined as potentially hazardous if they are sharp to the touch under casual handling conditions. The sub-assembly should not be considered unless the product is intended to be accessed as a sub-assembly e.g., an accessory part.

5.2.5 Maximum permitted temperatures

5.2.5.1 Touch temperature test

In addition to the Temperature tests defined in CSA C22.2 No. 62368-1/UL 62368-1, the surface temperature rise limits for accessible parts shall not exceed those specified under the Touch temperature test in 7.2.11.

5.2.5.2 Temperature test in recessed installation

When charging of the robot specifies that it is to be done in a recess area, the Temperature test, using maximum operating temperatures for materials, components and systems specified in CSA C22.2 No. 62368-1/UL 62368-1, shall be conducted in a recess area simulating the manufacturer's specification.

5.3 Abuse tests

In addition to the tests specified in CSA C22.2 No. 62368-1/UL 62368-1 for safeguards, the robot shall be subject to the following additional test.

5.3.1 Drop test

A robot that is intended to be carried shall be subject to the Drop test in 7.3.4.

6 Mobility

The requirements applicable to the robot are based on the application as specified in CSA C22.2 No. 62368-1/UL 62368-1. Additional requirements for the robotic function are covered in Clauses 6 – 12.

6.1 Indicators

Robots which require visible aids shall be provided with indicators designed to function with limited flicker which can trigger a reaction. Audible indicators shall be discernible by vulnerable persons but are not to exceed the specified limits. See Clause 10 and Annex D, Indicators, of this Standard for additional requirements and guidance on indicators.

6.2 Robot stop control

Robots shall be provided with the means by which to cause a stop. The initiation means can be triggered internally or externally.

NOTE Safety-related stop functions are covered in Clause 8.

6.3 Manipulators

The requirements in this Clause apply to legged robots and robots that have one or more manipulator(s) and/or end-effector(s) that are accessible to persons.

NOTE 1 Manipulator subassemblies evaluated to UL 1740 may be used, provided overall operation and construction comply with this Standard.

NOTE 2 ICT (Information and Computer Technology) equipment having fully contained integral manipulators with end-effectors for data storage and access are addressed by CSA C22.2 No. 62368-1/UL 62368-1, Special categories of equipment containing moving parts, and are considered out of scope of this Clause.

6.3.1 Interconnecting cables

In addition to meeting suitable ratings for interconnecting cables in CSA C22.2 No. 62368-1/UL 62368-1, all cables used for safe manipulator operation (i.e., cables, either internal or external, that bridge between moving parts of the robot) regardless of energy source classification shall have sufficient mechanical strength for their application. Wiring connections to a continuously moving part, or a part for which the degree of movement is appreciable, shall be:

– UL 62 flexible cord/cable of a Type such as S, SJ, SJE, SJO, SEO, SJT, SJTO, SJEO, SO, ST, SE, or STO flexible cord; or

– UL 758 appliance wiring material of a suitable rated voltage, temperature, and flammability for the interconnected circuits, and provided with mechanical construction to support ongoing flexibility such as a supplemental jacket over the conductors.

Compliance is determined based on testing in accordance with the test in 7.5.1, Endurance test, and the appropriate requirements of CSA C22.2 No. 62368-1/UL 62368-1 or CSA C22.2 No. 60335-1/UL 60335-1.

6.3.2 Range of motion

Means shall be provided to limit the range of motion of robot manipulator(s) and/or end-effector(s). The means provided shall not themselves cause a risk of pain, injury, or entrapment to persons. If mechanical stops are used, they shall be subjected to the test in 7.5.2, Mechanical hardstop test. If safety function(s) are used, see Clause 8.

NOTE Means complying with UL 1740, Limiting robot motion, are considered to meet these requirements.

6.3.3 Gripper end-effectors

Robots with gripper end-effectors shall be provided with means to release the gripper in an emergency, i.e., if a person is entrapped by the gripper. The gripper release shall comply with the test in 7.5.4, Gripper release test, and if the gripper release is performed by a control system, the gripper release function shall comply with Clause 8.

6.3.4 Concurrent and/or divergent motion

Robots with manipulators that are permitted to move while the robot's mobile platform is moving, and/or robots with multiple manipulators that are permitted to move at the same time, whether coordinated or independently, shall maintain safe operation. Safety functions responsible for the robot maintaining safe operation during simultaneous movement, or that prevent simultaneous movement, shall comply with Clause 8.

7 Testing

7.1 Robot specifications

The intended use and operational limits of the robot shall be specified by the manufacturer, consisting of declaration of the parameters specified in Table B.1 – Table B.3 in Annex B, Required Information for Robot Specification.

7.2 Tests for mobility safeguards

7.2.1 General

Robotic function safeguards shall be suitable for the robot specification such that they protect an operator and others in the use environment from hazards introduced by independent robot movement without human intervention. Such hazards include those arising from motion itself, the robot shape and size, sensor obfuscation, pre-programmed and learned decisions and actions, lack of situational awareness, and localization and navigation errors.

The performance of a robot shall be investigated by subjecting representative sample(s) of the robot to the robotic function tests described in this Clause, in addition to the tests in the referenced standards that cover non-robotic functions (i.e., CSA C22.2 No. 62368-1/UL 62368-1 or CSA C22.2 No. 60335-1/UL 60335-1).

During the robotic function tests described in this Clause, all functions that are not safety-related that could act prior to and/or interfere with safety functions shall be disabled or otherwise modified so that they do not influence the results of these tests.

EXAMPLE A non-safety-related navigation function using SLAM (simultaneous localization and mapping) data that directs the robot around an obstacle should be disabled or otherwise modified during these tests to allow the protective stop, safety-related speed, etc. safety functions to act.

7.2.2 General testing requirements

7.2.2.1 Conditions

Operating conditions include but are not limited to:

– Tests are carried out with the robot and any movable part of it, including doors, drawers, manipulators, end-effectors (including end-effector orientation), and other such parts, placed in the most unfavorable position based on the robot specification;

EXAMPLE During the Robot stability test in 7.2.4, a robot's manipulator could be fully extended away from the main body of the robot, potentially impacting its balance while the robot traverses a ramp.

– Carried out under intended use and abnormal operation conditions as specified in Normal operating condition tests, Abnormal operating condition tests and Single fault condition tests of CSA C22.2 No. 62368-1/UL 62368-1. This shall include failures of sensor units and individual sensors that could impair safety-related control systems;

– At the most unfavorable speed based on the robot specification;

EXAMPLE During the Obstacle detection test in 7.2.5, the robot could be operated at its maximum rated speed, potentially impacting its reaction and stopping time while the robot attempts to avoid an obstacle.

– At an ambient temperature between 10 °C – 40 °C;

NOTE 1 Robots are additionally subjected to a Thermal cycling test (see 7.4.9).

– In the most unfavorable conditions based on the robot specification and center of gravity;

EXAMPLE With the robot loaded, unloaded, and/or manipulating a load; this includes simultaneous movement of manipulator(s) and the overall robot when applicable.

– In the most unfavorable ambient lighting conditions based on the robot specification as follows:

  – A minimum of 50 lux (5 foot-candles); and

  – A maximum of 1500 lux for indoor robots or 10000 lux for outdoor robots.

EXAMPLE Some sensors can have trouble detecting obstacles in dark and/or bright conditions.

NOTE 2 Extremely bright conditions, i.e. ones that could interfere with safety-related sensors, are taken into consideration in the Light conditions test. See 7.2.9, Light conditions test.

7.2.2.2 Results

Unless otherwise specified, during and after the following tests, all robots shall:

– Not exceed the vertical length, speed and mass declared by the manufacturer;

– Have the mechanical strength required, be constructed to withstand mobility / manipulation and load handling that can be expected in specified operating conditions. Robot safeguards shall not be compromised during the tests;

– Not overturn or topple due to change in elevation within the robot specification;

– Not have uncontrolled lateral movement;

– Not have unintended drop of robot parts or loads when in motion;

– Robots not intended to make contact with safety-related objects, pets or persons shall not make contact during the tests specified in Clause 7; and

– Robots intended to make contact with safety-related objects, pets or persons shall maintain safe force limits of 50 N.

NOTE 1 Refer to research project No. FP-0317: Collaborative robots – Investigation of pain sensibility at the Man-Machine-Interface for source of 50 N.

NOTE 2 Requirements for robots intended to safely apply forces of greater than 50 N on safety-related objects, pets or persons are under consideration.

7.2.3 Floor surfaces

All robots shall be tested on a hard, even, and horizontal floor surface. For robots that operate indoors only, examples of test surfaces include, but are not limited to wood, laminate, vinyl, tile, or reflective tile. For robots that can operate outdoors, examples of test surfaces include, but are not limited to concrete, asphalt, or gravel.

A second test surface shall additionally be used during testing if the robot includes soft test surfaces in the robot specification. For robots that operate indoors only, examples of soft test surfaces include, but are not limited to carpets (see IEC 62885-2) or rubber mats. For robots that can operate outdoors, examples of soft test surfaces include, but are not limited to lawn, turf, dirt, or sand.

The soft test surface shall be used in addition to the hard test surface during the following tests:

– 7.2.4, Robot stability test;

– 7.2.4.1, Elevation change test; and

– 7.2.5, Obstacle test.

Additional floor surfaces shall be considered by the manufacturer as part of their verification and validation activities for functional safety. See 8.4.5, Additional test cases to consider in functional safety verification and validation activities.

7.2.4 Robot stability test

The robot shall be operated, including docking and undocking from its external power supply (battery charger), as per the robot specification. The robot supporting surface shall be smooth, flat and of sufficient size that the robot can achieve operational speed. The robot shall remain stable while operating in the following elevation changes and loading conditions:

– Transition to a ramp having a 5° slope (indoor robots) or 15° slope (outdoor robots) down from the horizontal and also considering the robot turning 90° to 180°;

– Transition to a ramp having a 5° slope (indoor robots) or 15° slope (outdoor robots) up from the horizontal and also considering the robot turning 90° to 180°;

– For outdoor robots and/or robots used in wet locations that are rated to operate in temperatures less than 0 °C, transition to a wet glass ramp having a 5° slope (indoor robots) or 15° slope (outdoor robots) down from the horizontal; and

– Operated on a flat, smooth horizontal surface and with loads up to but not exceeding 150 % of the marked payload.

Elevation changes or loading conditions specified above that are excluded from the robot's specification do not require consideration during the test if there are safety function(s) in place to detect and avoid those elevation changes or loading conditions that comply with the requirements of Clause 8.

Additional situations that could impact the ability of the robot to remain stable shall be considered by the manufacturer as part of their verification and validation activities for functional safety. See 8.4.5, Additional test cases to consider in functional safety verification and validation activities.

7.2.4.1 Elevation change test

The robot shall be operated per the manufacturer's instructions with the identified elevation changes in the path of the robot in motion under the following conditions. In each case the robot shall safely traverse the elevation change without any loss of stability.

– Stairs as follows in upward and downward directions;

  – Riser height shall be from 15.24 cm to 19.05 cm;

  – Stair width a minimum of 55.88 cm between vertical barriers; and

  – Tread depth a minimum of 30.48 cm ±5.08 cm.

  NOTE Representative of fixed stairway specification by the Occupational Safety and Health Administration (refer to bibliography).

– Smaller depressions with widths as follows:

  – 50 % of robot width;

  – 100 % of robot width;

  – 1 m; and

  – 2 m.

– Floor transitions:

  – On a hard test surface, transition over a metal floor threshold of 15 mm height;

  – Transition from a hard test surface to a soft test surface over a metal floor threshold of 15 mm height; and

– Transition from a soft test surface to a hard test surface over a metal floor threshold of 15 mm height.

Exception: Robots that do not exceed 7 kg are exempt from the floor transitions tests when the robot's shape is deemed not capable of causing pain or injury if the robot were to tip over.

Elevation changes specified above that are excluded from the robot's specification do not require consideration during the test if there are safety function(s) in place to detect and avoid those elevation changes that comply with the requirements of Clause 8.

Additional elevation changes and floor transitions shall be considered by the manufacturer as part of their verification and validation activities for functional safety. See 8.4.5, Additional test cases to consider in functional safety verification and validation activities.

7.2.5 Obstacle test

The robot shall be operated per the manufacturer's instructions with the identified obstacles in the path of the robot and robot subassembly (e.g., manipulator and/or end-effector) in motion under the following conditions. The robot shall start at a distance that allows the robot to reach its maximum speed before encountering the obstacle. The robot shall either stop prior to impacting the obstacle, avoid the obstacle or impact the obstacle with a force not exceeding the specified force in 7.2.2, General testing requirements. These tests shall be repeated for each robot subassembly that moves independently from the mobile robot.

a) Adult torso

– Cylinder of 200 mm diameter x 600 mm length;

– Placed horizontally; and

– Material with reflectance between 5 % – 10 % using black felt or coarse fabric.

NOTE 1 Source ISO 18646-2

b) Adult lower leg

– Cylinder of 70 mm diameter x 400 mm height;

– Placed vertically; and

– Material with reflectance between 5 % – 10 % using black felt or coarse fabric.

NOTE 2 Source ISO 18646-2

c) Child's body

– Toddler dummy (14.5 kg) with mass distribution specified in Table 2 and dimensions specified in Figure 1. The dummy shall be placed in both standing and sitting positions;

– Material with reflectance between 5 % – 10 % using black felt or coarse fabric; and

– Infant dummy (9.4 kg) with mass distribution specified in Table 3 and dimensions specified in Figure 2. The dummy shall be placed in both crawling and laying flat positions.

d) Wall

– Plate resembling wall segment; both wood (e.g. pine) plate and uncolored acrylic plate with transmissivity of more than 95 %; and

– 1.5 m height, 1 m width.

e) Table

– Plate with four legs resembling a table; both wood (e.g. pine) and metal (e.g. steel) legs;

– Height: 0.7 m – 0.8 m;

– Width: 1.5 m – 2.0 m;

– Depth: 0.5 m – 0.8 m;

– Thickness of legs: 0.03 m – 0.05 m; and

– Weight: 16.6 kg minimum.

f) Semi-solid wall (railing or fence)

– Aluminium or metal material of dimensions shown below in Figure 3.

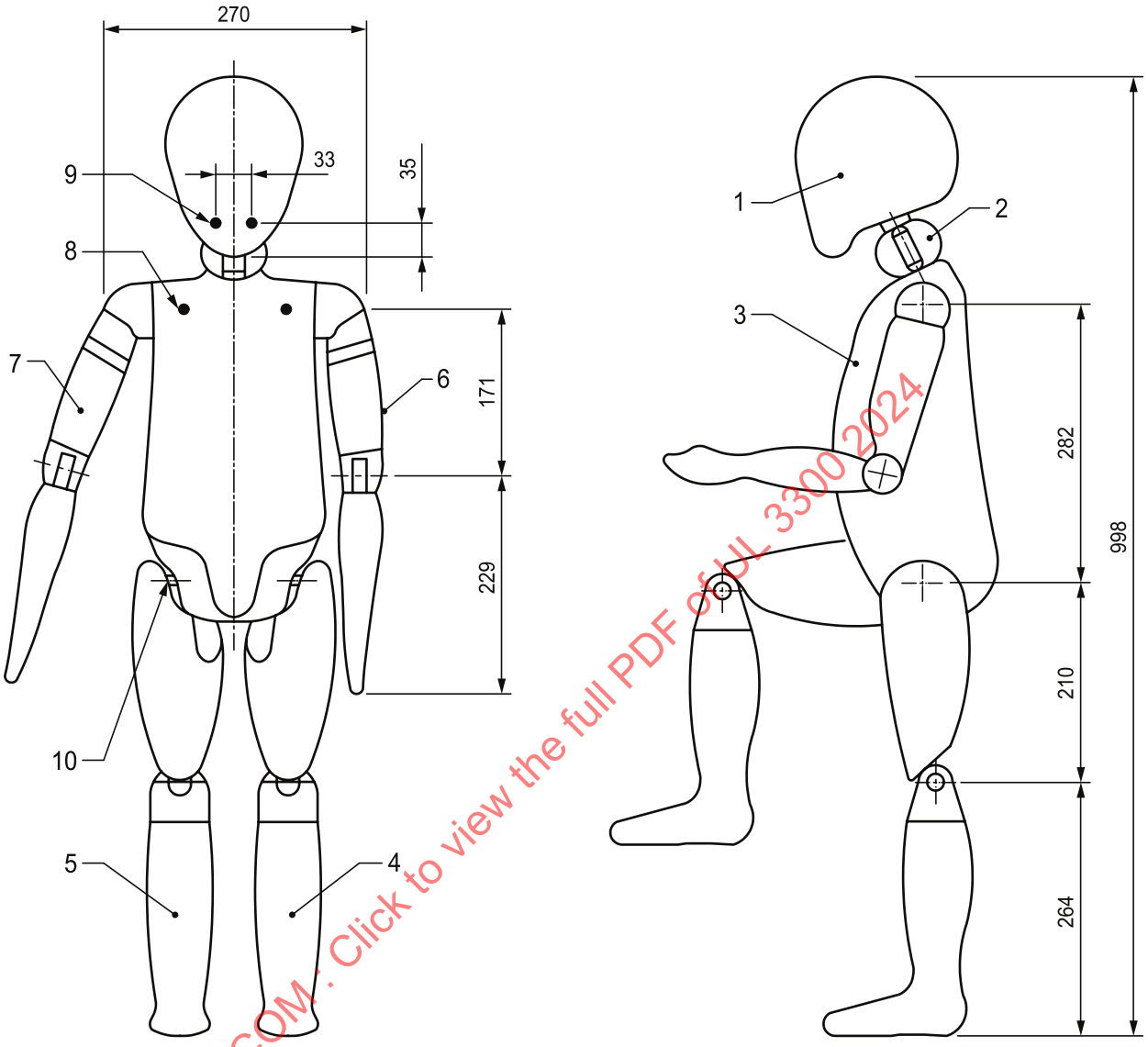
Additional obstacles shall be considered by the manufacturer as part of their verification and validation activities for functional safety. See 8.4.5, Additional test cases to consider in functional safety verification and validation activities.

Table 2
Target Mass Distribution and Density of Body Segments of 14.5 kg Manikin

Component	Mass g	Volume cm^3	Density g/cm^3
Head and neck	2740	2450	1118
Torso	6800	6545	1039
Upper leg (x2)	897	834	1075
Lower leg (x2)	859	803	1070
Upper arm (x2)	408	382	1068
Lower arm (x2)	300	285	1053
Total	14.5 kg	13,603 cm^3	1034 g/cm^3

Table 3
Target Mass Distribution and Density of Body Segments of 9.4 kg Manikin

Component	Mass g	Volume cm^3	Density g/cm^3
Head and neck	2070	1888	1096
Torso	4780	4635	1031
Upper leg (x2)	514	480	1071
Lower leg (x2)	405	380	1065
Upper arm (x2)	202	192	1052
Lower arm (x2)	153	145	1055
Total	9.4 kg	8917 cm^3	1054 g/cm^3



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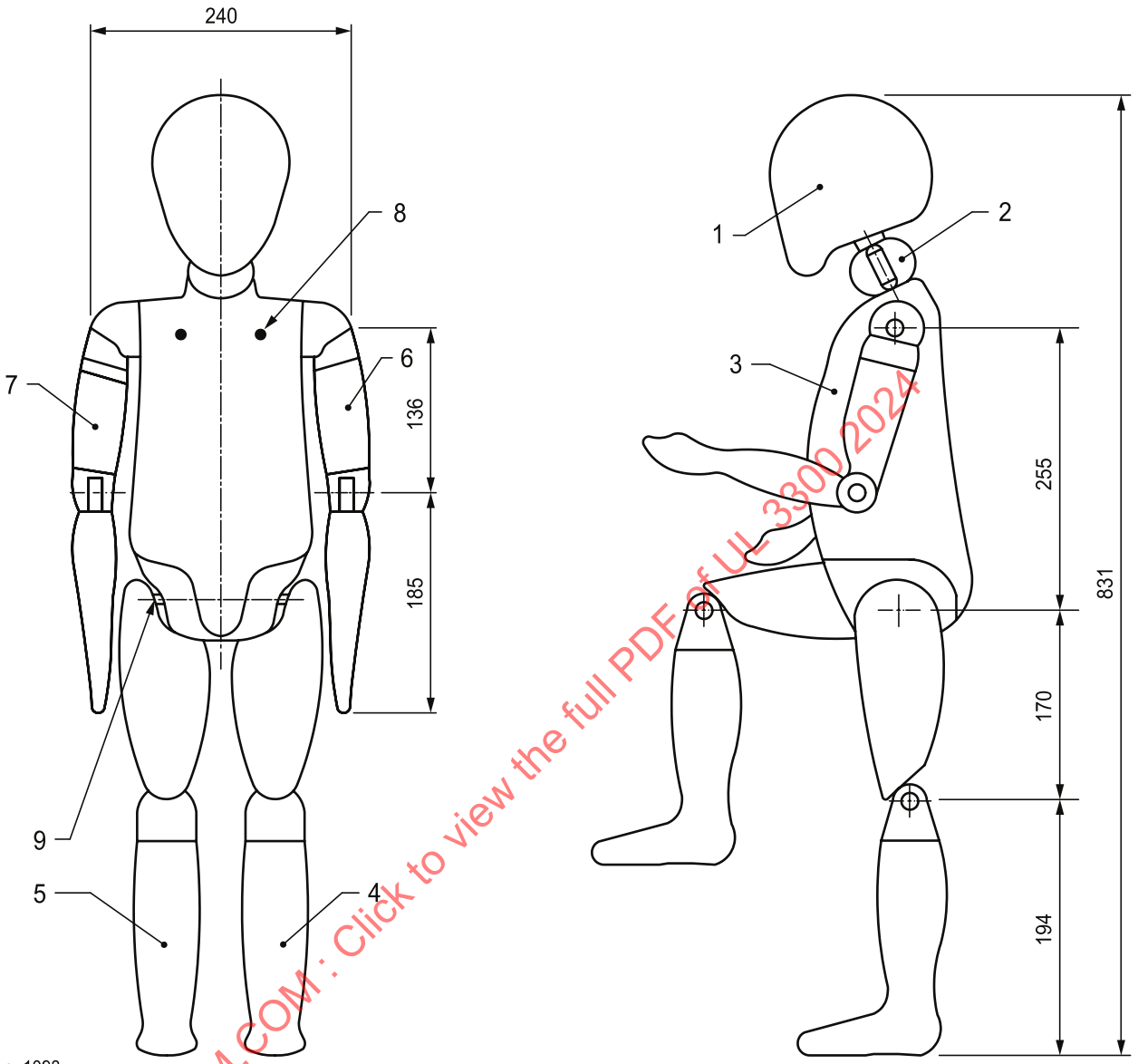
Key

1 head assembly
2 neck assembly
3 torso assembly
4 left leg assembly
5 right leg assembly
6 left arm assembly
7 right arm assembly
8 shoulder fixing pin
9 mouth position pin (yellow)
10 hip fixing pin

Figure 1

Scale Drawing of 14.5 kg Manikin



Key

1 head assembly
2 neck assembly
3 torso assembly
4 left leg assembly
5 right leg assembly
6 left arm assembly
7 right arm assembly
8 shoulder fixing pin
9 hip fixing pin

Figure 2

Scale Drawing of 9.4 kg Manikin

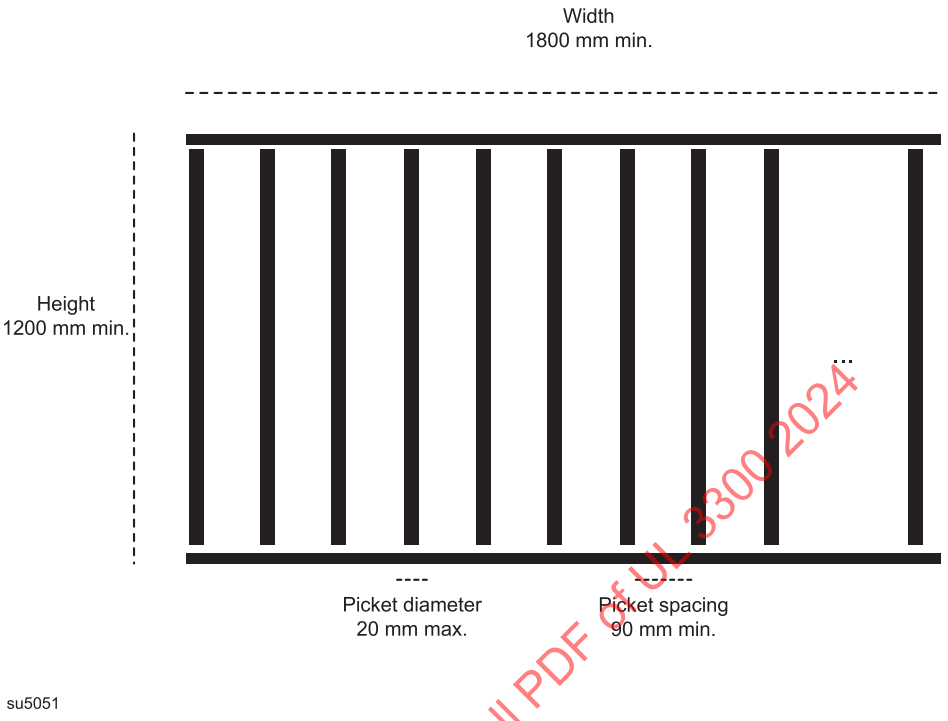


Figure 3

Semi-Solid Wall Dimensions

7.2.6 Vibration test

7.2.6.1 General

The as-received robot shall be subject to vibration tests as specified in 7.2.6.2, Robots only for indoor use on smooth surfaces with no manipulators, or 7.2.6.3, All other robots, based on the robot specification. After the robot is subject to the required test:

a) The robot shall not emit flame or molten metal or become a risk of fire, electric shock, or injury to persons;

b) There shall be no loosening of parts that reduce the effectiveness of the equipment safeguards;

c) The battery management system shall not be adversely affected; and

d) The robot shall comply with 7.6, Additional evaluation of compliance.

During the tests, the robot shall be fastened in its normal position(s) of use by means such as screws, clamps, braces, or straps around the robot so as to secure the entire robot to the vibration generator.

In lieu of testing the entire robot system, individual subassemblies performing safety functions, including (but not limited to) sensors, control systems, batteries, and motors shall be subject to the tests. After the subassemblies are subject to the tests, they shall be reintegrated into the robot and the criteria of a) – d) above shall be assessed on the entire robot system.

7.2.6.2 Robots only for indoor use on smooth surfaces with no manipulators

For robots intended for indoor use only, operation on smooth surfaces only, and without manipulators:

The test shall consist of vibration for 30 min at a frequency of 10 Hz to 55 Hz and back to 10 Hz, with a sweep rate of one octave per minute. The amplitude shall be 0.35 mm peak-to-peak displacement in a vertical plane.

7.2.6.3 All other robots

For all other robots:

The test shall be performed in accordance with IEC 60068-2-64 per Method of covering enclosures with foil for measurement and tests of UL/ULC 2271. The robot is to be subjected to random vibration along three perpendicular axes in space in a sequence starting with the vertical axes (Z) and ending with the longitudinal axis (X). The robot shall be subjected to vibration in each axis for 21 h. For each axis, the frequency shall be varied from 5 Hz to 200 Hz with power spectral density (PSD) for the vertical (Z) axis, the longitudinal (X) axis, and the transverse (Y) axis as outlined in ISO 12405-4.

7.2.7 Mass and vertical length measurement

The fully assembled robot, with all attachments but excluding the docking station or external power supply (charger), shall be weighed and its vertical length measured with the robot it its most unfavorable configuration and condition.

EXAMPLE A robot's manipulator could be fully extended above the main body of the robot, changing the robot's maximum vertical length.

The robot shall not be found to have a mass or vertical length more than the maximums declared by the manufacturer.

7.2.8 Battery discharge test

The robot, including any manipulator(s) and end-effector(s), shall be operated continuously as intended with its rated payload, and at its maximum speed/acceleration until the robot has entered a steady-state (e.g., through execution of the fail-safe routine in 8.11.4, full depletion of the battery, etc.). The robot shall stop safely without unintentional release of the payload. The robot's battery shall then be fully charged, after which time the robot shall comply with 7.6., Additional evaluation of compliance.

7.2.9 Light conditions test

The robot, including any manipulator(s) and end-effector(s), shall be operated as intended with its rated payload, and at its maximum speed/acceleration, while subjected to the following four lighting conditions:

a) Low-intensity light conditions of 50 lux;

b) High-intensity light conditions as follows: 10,000 lux for robots intended for indoor use only, or 100,000 lux for all other robots;

c) Transition from low-intensity to high-intensity light conditions as specified in a) and b), respectively; and

d) Transition from high-intensity to low-intensity light conditions as specified in b) and a), respectively.

The robot shall either enter a steady-state with the robot stopping safely or continue to operate, without unintentional release of the payload. If the robot continues to operate, the robot shall additionally comply with the light conditions above repeated during 7.6, Additional evaluation of compliance.

Light conditions specified in a) and b) above that are excluded from the robot's specification are permitted to be replaced with the minimum and/or maximum lighting conditions declared in the robot's specification when there are safety function(s) in place to detect and inhibit robot operation in the light conditions specified in a) and b) above. The safety function(s) shall comply with the requirements of Clause 8.

7.2.10 Power supply test

If a single-fault, abnormal or other condition exists within the robot's power supply(s), including its battery, that could cause the robot to suddenly lose power, the following test shall be conducted:

The robot, including any manipulator(s) and end-effector(s), shall be operated as intended with its rated payload, and at its maximum speed/acceleration. Power shall be removed from the robot. The robot shall stop safely without unintentional release of the payload. Power shall then be restored and the robot shall comply with 7.6, Additional evaluation of compliance.

7.2.11 Touch temperature test

The Touch temperature test defined in CSA C22.2 No. 62368-1/UL 62368-1 shall be conducted. During the test, the surface temperature for accessible parts shall not exceed 50 °C if the surface is substantially metal, 55 °C if the surface is ceramic or glass, or 60 °C if the surface is wood or plastic.

7.2.12 Sharp edge test

NOTE Test procedure, specifications and compliance defined in Code of Federal Regulations (CFR) 16, Part 1500.49.

7.2.12.1 Operation

The test shall be performed with a sharp edge tester which contains a cylindrical mandrel capable of rotation at a constant velocity. The full circumference of the mandrel shall be wrapped with a single layer of polytetrafluoroethylene tape as specified under specifications below. The mandrel shall be applied to the edge to be tested with a normal force of 6 N such that the edge contacts the approximate center of the width of the tape as shown in Figure 4 of this Clause. The mandrel shall be rotated through one complete revolution while maintaining the force against the edge constant. Linear motion of the mandrel along the line of the edge shall be prevented. The edge shall be identified as sharp if it completely cuts through the tape for a length of not less than 13 mm at any force up to 6 N.

7.2.12.2 Test procedure

The edge of the sample to be tested shall be held in such a manner that it does not move during the test. If the full mandrel force of 6 N causes the edge to bend, a reduced mandrel force may be used.

Part of the test sample may need to be removed to allow the sharp edge testing device to test an edge that is accessible. Dismantling of the test sample could affect the rigidity of the edge in question. The sharp edge test shall be performed with the edge supported so that its stiffness approximates but is not greater than the edge stiffness in the assembled sample.

Conduct of a sharp edge test is as follows: Wrap one layer of polytetrafluoroethylene tape, described in specifications below, around the full circumference of the mandrel (shown below) in an unstretched state. The ends of the tape shall be either butted or overlapped not more than 2.5 mm. Apply the mandrel, at the approximate center of the tape, to the edge of the test sample with a force of 6 N measured in a direction

at right angles to the mandrel axis. The mandrel shall be placed so that its axis is at 90° ±5° to the line of a straight test edge or 90° ±5° to a tangent at the point of contact with a curved test edge. The point of contact between the test edge and the mandrel shall be in the approximate center of the width of the tape. The axis of the mandrel may be positioned anywhere in a plane which is at right angles to either the line of a straight test edge or to a tangent at the point of contact with a curved test edge. The operator should seek the orientation most likely to cause the edge to cut the tape. Maintain the force against the edge and rotate the mandrel through one complete revolution while preventing any linear motion of the mandrel along the edge. Release the mandrel from the edge and remove the tape without enlarging any cut or causing any score to become a cut. A cut in the tape with a length of not less than 13 mm identifies an edge as sharp.

NOTE The test instruments will be calibrated to ensure that the force with which the mandrel is applied to a test edge does not exceed 6 N.

7.2.12.3 Specifications for sharp edge test equipment

The following specifications shall apply to the equipment to be used in the sharp edge test.

a) The rotation of the mandrel shall produce a constant tangential velocity of 25.4 mm/s ± 2.0 mm/s during the center 75 % of its rotation and shall have a smooth start and stop.

b) The mandrel shall be made of steel. The test surface of the mandrel shall be free of scratches, nicks, or burrs and shall have a surface roughness no greater than 0.40 µm. The test surface shall have a hardness no less than 40 as measured on the Rockwell "C" scale. The diameter of the mandrel shall be 9.35 mm ±0.12 mm. The mandrel shall be of suitable length to carry out the test.

c) The tape shall be pressure-sensitive polytetrafluoroethylene high temperature electrical insulation tape. The thickness of the polytetrafluoroethylene backing shall be between 0.066 mm and 0.089 mm. The adhesive shall be pressure-sensitive silicone polymer with a nominal thickness of 0.08 mm. The width of the tape shall not be less than 6 mm. While conducting sharp edge tests the temperature of the tape shall be maintained between 21.1 °C and 26.6 °C.

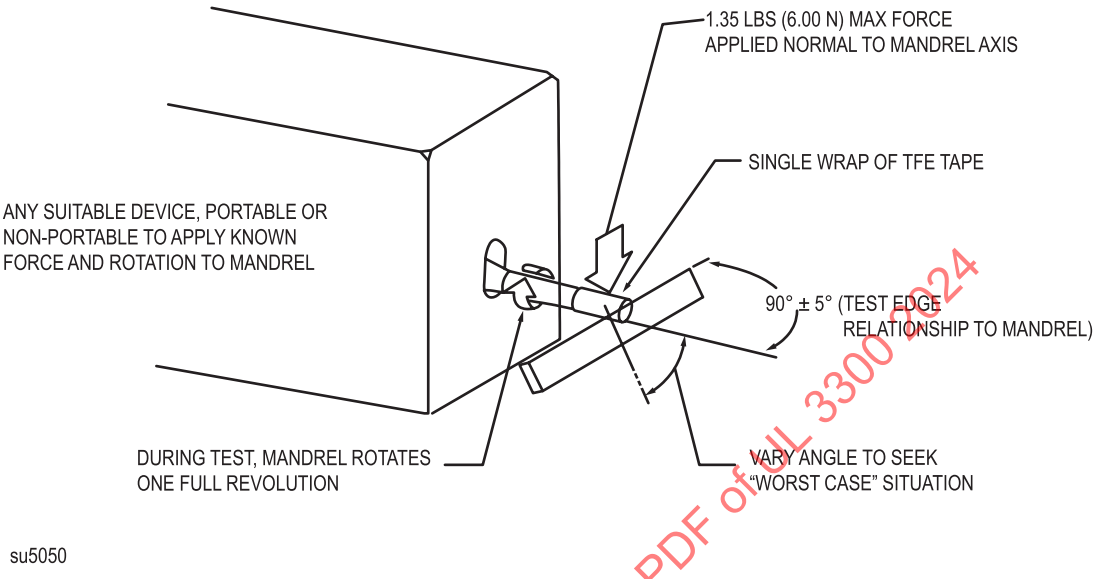


Figure 4

Sharp Edge Test

7.2.13 Access to small parts testing

7.2.13.1 Torque test for removal of components

Any robot with a part or assembly that a vulnerable person can grasp with at least the thumb and forefinger or the teeth shall be subject to this test. The amount of torque shall be 0.47 N·m. The loading device used in the test shall be a torque gauge, torque wrench, or other appropriate device having an accuracy of ±0.02 Nm. A clamp capable of holding the test component firmly and transmitting a torsional force shall be used. The clamp is fastened to the test object or component with the robot fastened rigidly in any reasonable test position. The torque shall be applied evenly within a period of 5 s in a clockwise direction until either (1) a rotation of 180° from the original position has been attained, or (2) the required torque is exceeded. The maximum rotation or required torque shall be maintained for an additional 10 s. The torque shall then be removed and the test component permitted to return to a relaxed condition. This procedure shall then be repeated in a counterclockwise direction. Projections, parts, or assemblies that are mounted rigidly on an accessible rod or shaft designed to rotate along with the projections, parts, or assemblies shall be tested with the rod or shaft clamped to prevent rotation. If a component that is attached by a screw thread that has been assembled by the manufacturer, or that has been assembled to the manufacturer's instructions, becomes loosened during application of the required torque, continue to apply the torque until either (1) the required torque is exceeded, or (2) the part disassembles. The test should be terminated if it becomes obvious that the part under test will continue to rotate at less than the required torque limit and will not disassemble.

If the part disassembles, evaluate it for compliance with the appropriate requirements. If the disassembly exposes an accessible component that can be grasped as noted above, repeat the torque test on that component.

7.2.13.2 Tension test for removal of components

Any projection of a robot that a vulnerable person can grasp with at least the thumb and forefinger or teeth shall be subjected to this test.

The tension test shall be performed on the same components of the robot subjected to the torque test described in 7.2.13.1, Torque test for removal of components. The amount of force used shall be 69 N. A clamp capable of applying a tension load to the test component shall be applied in a manner that will not affect the structural integrity of the attachment between the component and the robot. The loading device shall be a self-indicating gauge or other appropriate means having an accuracy of ±2 N. With the test sample fastened in a convenient position, an appropriate clamp shall be attached to the test object or component. The required tensile force shall be applied evenly, within a period of 5 seconds, parallel to the major axis of the test component, and maintained for an additional 10 seconds. The tension clamp shall then be removed, and a second clamp suitable for applying a tension load perpendicularly to the major axis of the test component shall be attached to the test object component. The required tensile force shall be applied evenly, within a period of 5 seconds, perpendicularly to the major axis of the test component and maintained for an additional 10 seconds.

7.2.14 Locked rotor test

Each drive motor shall be operated in a locked-rotor condition and assessed according to the criteria in CSA C22.2 No. 62368-1/UL 62368-1 or CSA C22.2 No. 60335-1/UL 60335-1. If correct movement of the motor is necessary for safe operation of the robot, including any manipulator, i.e., it is part of or can influence a safety function, the robot shall maintain safe operation by initiating a robot stop and generating an awareness signal (i.e., fail-safe routine). Safety functions responsible for complying with this test shall be assessed per Clause 8.

NOTE The Locked drive motor test in UL 1740 is considered to meet this requirement.

7.2.15 Motor brake test

If a mechanical motor brake is provided, each drive motor shall be operated with its brake applied for 4 hours or ultimate results are obtained, and with its brake disabled. Results shall be assessed according to the criteria in CSA C22.2 No. 62368-1/UL 62368-1, Motors, or CSA C22.2 No. 60335-1/UL 60335-1, Abnormal operation, and the applicable Part 2 of UL 60335. If correct operation of the brake is necessary for safe operation of the robot, including any manipulator, i.e., it is part of or can influence a safety function, the robot shall maintain safe operation by initiating a robot stop and generating an awareness signal (i.e., fail-safe routine). Safety functions responsible for complying with this test shall be assessed per Clause 8.

NOTE The Locked brake test in UL 1740 is considered to meet this requirement.

7.3 Safeguards provided for robot shape and size

Robots shall have adequate mechanical strength and be constructed to withstand such rough handling that can be expected in normal operation and to provide adequate protection against personal injury in normal use.

The robot shall not tip over, safety critical controls and sensor units shall continue to function as intended, and the intended function of basic safeguards shall not be impaired. Components of the traction means shall be located or protected so as to prevent injury. Compartments and storage areas shall not entrap persons and any doors, lids or covers shall be non-locking.

Compliance is checked by inspection and the tests of 7.3.1, Downward force test – 7.3.4, Drop test.

7.3.1 Downward force test

The robot is subject to a constant downward force applied at any point on the robot wider than 125 mm or at a rigid, or greater flat surface within 200 mm of the robot supporting surface that could serve as a step or stair.

The applied force is 800 N for seat depths greater than 350 mm and 400 N for those of 350 mm or less. The force is applied by means of a suitable test apparatus having a flat surface of approximately 125 mm x 200 mm or 125 mm, as appropriate for the surface under test. The downward force is applied with the complete flat surface of the test apparatus in contact with the robot, however the test apparatus need not be in full contact with uneven surfaces (for example, corrugated or curved surfaces).

NOTE Seat depth is measured in the direction of robot travel.

7.3.2 Moving components

The robot safeguard(s) protecting against access to moving components and robot parts are:

– For traction means (e.g. motor parts such as shaft, gears, etc.), subject to a force not exceeding 5 N applied between the supporting surface and the robot by means of a test probe that is similar to test probe in Determination of accessible parts of CSA C22.2 No. 62368-1/UL 62368-1 but having a 50 mm diameter circular stop face. The probe shall not come into contact with a moving part; and

– For both traction means and accessible joints between movable robot parts, subject to the requirements of CSA C22.2 No. 62368-1/UL 62368-1, Mechanically-caused Injury.

This test is not applicable to components and robot parts that stop moving prior to being contacted through a safety function that complies with the requirements of Clause 8.

NOTE See CSA C22.2 No. 62368-1/UL 62368-1, Determination of accessible parts for details.

7.3.3 Enclosed compartment test

For robots provided with an enclosed compartment having a user access opening dimension exceeding 200 mm and an interior volume of 60 dm^3, it shall take less than a force of 70 N to open the access cover, lid or door from the inside. The robot shall be tested with a fully charged battery, a fully discharged battery, and while charging in its docking station. The force is applied perpendicular to the plane of the closed door, lid or cover at a point furthest from the hinges accessible from the inside.

NOTE The force can be applied to the outside of the door.

7.3.4 Drop test

Robots that are intended to be carried, operate on table-top or desktop, or are inherently unstable (e.g., legged robots), shall be subjected to a drop test according to CSA C22.2 No. 62368-1/UL 62368-1 Drop test. The drop shall be conducted at the worst-case configuration and as follows:

– For robots intended to be carried, the drop height shall be 1000 mm ±10 mm;

NOTE 1 Tested as handheld equipment per CSA C22.2 No. 62368-1/UL 62368-1.

– For robots intended to operate on table-top or desktop, the drop height shall be 750 mm ±10 mm; or

NOTE 2 Tested as desk-top equipment per CSA C22.2 No. 62368-1/UL 62368-1.

– For robots that are inherently unstable (e.g., legged robots), the drop shall be conducted with the robot standing on the test surface and then tipped over.

The drop surface to be used shall be the most unfavorable surface specified in the robot specification.

EXAMPLE A firm/dense surface such as a hardwood floor; a jagged stone surface.

If not specified, the drop surface specified in CSA C22.2 No. 62368-1/UL 62368-1 Drop test shall be used.

After the drop test, the evaluation test portion of CSA C22.2 No. 62368-1/UL 62368-1 Drop test of equipment containing a secondary lithium battery shall be followed to confirm that the battery is operating normally. The robot shall not pose a risk of fire, electric shock, or personal injury, there shall be no loosening of parts that reduce the effectiveness of equipment safeguards, the battery management system shall not be adversely affected, and the robot shall comply with 7.6, Additional evaluation of compliance.

7.4 Environmental stress tests

7.4.1 General

A robot shall not be adversely affected by environmental stresses. Compliance is checked by the tests specified in 7.4.2, Power supply voltage dips, variation, interruptions – 7.4.10, Exposure to moisture. After the robot is subject to the tests:

a) The robot shall not emit flame or molten metal or become a risk of fire, electric shock, or injury to persons;

b) There shall be no loosening of parts that reduce the effectiveness of the equipment safeguards;

c) The battery management system shall not be adversely affected; and

d) The robot shall comply with 7.6, Additional evaluation of compliance.

NOTE The tests specified below are consistent with the electromagnetic immunity tests specified in UL 60335-1, and UL 60730-1, Electromagnetic compatibility (EMC) requirements – immunity. If there are discrepancies in test procedures or test levels with the functional safety standard used, the tests specified in 7.4.2, Power supply voltage dips, variation, interruptions – 7.4.10, Exposure to moisture, prevail.

7.4.2 Power supply voltage dips, variation, interruptions

The robot, while connected to its charging equipment, shall be subjected to power supply voltage dips, variation and interruptions, class 3 in accordance with IEC 61000-4-11. The values specified in IEC 61000-4-11, Preferred test levels and durations for voltage dips and Preferred test levels and durations for short interruptions, are applied at zero crossing of the supply voltage.

7.4.3 Surge immunity

The robot, while connected to its charging equipment, shall be subjected to surge immunity in accordance with IEC 61000-4-5, five positive impulses and five negative impulses being applied at the selected points. An open circuit test voltage of 2 kV is applicable for the line-to-line coupling mode, a generator having a source impedance of 2 Ω being used. An open circuit test voltage of 4 kV is applicable for the line-to-earth coupling mode, a generator having a source impedance of 12 Ω being used.

7.4.4 Electrical fast transient bursts

The robot, while connected to its charging equipment, shall be subjected to electrical fast transient bursts in accordance with IEC 61000-4-4. Test level 3 shall be used for signal and control lines. Test level 4 for the power supply lines. A repetition rate of 5 kHz shall be used. The bursts are applied for 2 min with a positive polarity and for 2 min with a negative polarity.

7.4.5 Electrostatic discharge test

The robot shall be subjected to the Electrostatic discharge test in accordance with IEC 61000-4-2. Test level 4 shall be used. Ten discharges having a positive polarity and ten discharges having a negative polarity are applied at each preselected point.

7.4.6 Injected currents

The robot, while connected to its charging equipment, shall be subjected to injected currents in accordance with IEC 61000-4-6. Test level 3 shall be used. During the test, all frequencies between 0.15 MHz – 80 MHz are applied.

NOTE The dwell time for each frequency is to be sufficient to observe a possible malfunction of the safety-related control.

7.4.7 Radiated electromagnetic fields

The robot shall be subjected to radiated electromagnetic fields as specified in IEC 61000-4-3. The frequency ranges tested shall be:

– 80 MHz – 2.0 GHz, test level 3; and

– 2.0 GHz – 6.0 GHz, test level 2.

NOTE 1 The dwell time for each frequency is to be sufficient to observe a possible malfunction of the safety-related control.

NOTE 2 It can be necessary to repeat the tests under different conditions in order to determine compliance with this requirement.

7.4.8 Power frequency magnetic fields

The robot shall be subjected to power frequency magnetic fields as specified in IEC 61000-4-8. Test level 3 shall be applied.

7.4.9 Thermal cycling test

The robot shall be subjected to a thermal cycling test in accordance with IEC 60068-2-14, Test Nb: change of temperature with specified rate of change. The parameters of the test shall be as follows:

– During the test, the robot shall be in its "ready for use" state (i.e., powered-on and idle, on a flat surface, waiting for a command) at 25 °C;

– The low temperature (T_A) and high temperature (T_B) to be used during the test shall be the minimum and maximum ambient operating temperatures of the robot as declared by the manufacturer;

– The temperature change rate to be used during the test is 1 °K/min;

– The exposure time (t_1) at each temperature shall be 3 hours; and

– The test shall be conducted for two full temperature cycles.

7.4.10 Exposure to moisture

If not already considered as part of the Type or IP rating enclosure assessment in 5.2.3, Environmental conditions, robots intended for outdoor and/or wet locations shall be subjected to water spray over the exposed surface of the robot for duration in accordance with the robot enclosure's Type or IP rating. After the test, the water spray shall not be sufficient to interfere with the correct operation of the equipment or impair safety. If the robot is operational after the test, the robot shall comply with 7.6, Additional evaluation of compliance.

7.5 Tests for robots with manipulators

7.5.1 Endurance test

Manipulator(s) and end-effector(s) of the robot shall be operated as intended while grasping and releasing their rated payload, and at their maximum speed and acceleration, through a minimum of 1000 cycles. During and after the test, the robot shall perform its intended function without unintentional release of the payload. In addition, wiring between sections of the robot is to be examined for damage and to determine if any conductors are broken or if individual strands have penetrated the insulation.

NOTE The following tests in UL 1740 are considered to meet this requirement: Endurance, End-Effector, and Flexing.

7.5.2 Mechanical hardstop test

If mechanical stops are employed, at the conclusion of the test in 7.5.1, Endurance test, the mechanical stops shall be capable of stopping robot motion under rated load, maximum speed conditions, and at maximum extension. There shall be no evidence of loss of mechanical integrity or safety function.

NOTE The End of travel hardstop test in UL 1740 is considered to meet this requirement.

7.5.3 Emergency movement test

Each axis of the robot shall be tested to determine if it is capable of emergency movement.

NOTE The Emergency movement of robot without drive power test in UL 1740 is considered to meet this requirement.

7.5.4 Gripper release test

Robots with gripper end-effectors shall be operated as intended with its rated payload. A robot stop shall be initiated, after which time there shall be no unintentional release of the payload. The gripper release shall then be actuated, after which time the payload shall be released.

NOTE If it is anticipated that the rated payload could cause risk of pain, injury, or damage when it is released, the rated payload may be substituted by an alternate payload that clearly indicates if the gripper has been released.

7.6 Additional evaluation of compliance

After the tests noted in Clause 7, additional evaluation of compliance shall be conducted to verify safe operation of the robot as follows:

– 7.2.4.1, Elevation change test, downward stair; and

– 7.2.5 Obstacle test, c) child's body.

If the Clause 7 test specifies that a certain event take place during the test (e.g., light transition), the event shall occur prior to the robot encountering the obstacle.

8 Safety-related Control Systems

8.1 Risk assessment

8.1.1 General

The manufacturer shall conduct a risk assessment to identify hazards, estimate risk, reduce risk by implementing protective measures including safety functions, and determine acceptability of residual risk depending on the robot specification. The principles described in ISO 12100 and ISO/TR 14121-2 may be used as guidance for the risk assessment.

NOTE 1 ISO 10218-2, UL 1740, and ISO/TS 15066 have considerations for collaborative robot applications.

NOTE 2 ISO/TR 23482-2 provides application guidance on applying risk assessment and risk reduction on personal care robots.

8.1.2 Define intended use and operational limits

The intended use, limitations of use, and reasonably foreseeable misuse of the robot shall be defined. See 7.1, Robot specifications.

8.1.3 Hazard identification

Hazards due to the robot application's intended use, limits of use, and/or reasonably foreseeable misuse shall be identified, including hazards associated with robot manipulators, as applicable.

Environmental conditions expected to be present over the lifetime of the robot, including (but not limited to) vibration, thermal variations, and exposure to moisture shall be considered.

Hazards shall focus on those related to the mobility and robotic functions of the robot, though hazards associated with non-robotic functions (e.g. electrical hazards) may also be identified.

8.1.4 Risk estimation

For hazards identified in 8.1.3, Hazard identification, risk estimation shall be carried out. If numeric values are used, an appropriate validation of the methodology shall be provided.

8.1.5 Risk reduction through implementation of protective measures

Safe design, protective measures including safety functions, and other safeguards that reduce risk shall be identified.

Safe design and protective measures shall be evaluated and tested in accordance with the requirements of this Standard. Safety functions shall be evaluated in accordance with 8.2, Safety functions – 8.16, Sensor configuration, calibration and servicing.

8.1.6 Determine acceptability of risk

The risk assessment shall show that all identified risks have been reduced to acceptable levels.

8.2 Safety functions

Safety-related control system(s) of the robot shall be provided with safety functions that reduce the risk of hazardous horizontal impact, hazardous vertical fall, hazardous entrapment and hazardous manipulator movement due to energy transfer being imparted to a person while using, interacting, or in the presence of the robot.

8.3 Hazard Classes for robotic mobility

For each hazard, the robot shall be assigned into one of the following three Classes per Table 4. The concept of Hazard Class is based on CSA C22.2 No. 62368-1/UL 62368-1 energy sources. Class 3 is assumed for each hazard unless sufficient rationale is provided in the manufacturer's risk assessment showing that a lower Class is appropriate. Refer to Annex E, Methods to Determine Maximum Capable Force, for guidance.

NOTE 1 Though thresholds for Hazard Classes are provided in 8.3, Hazard Classes for robotic mobility, the thresholds for pain or injury are not constant throughout the population. For example, for some hazards, threshold is a function of body mass; the lower the mass, the lower the threshold, and vice-versa. Other body variables such as age, state of health, skin characteristics, etc. also can impact the threshold. Furthermore, even where outward appearances otherwise appear equal, individuals differ in their thresholds of susceptibility to the same hazard.

Table 4
Classes for Each Hazard

Line	Hazard	Class 1	Class 2	Class 3
1	Horizontal Impact	Robot is not capable of exerting a force in excess of 50 N on humans or other obstacles[f]	Robot is not capable of exceeding the limits for quasi-static and transient contact specified in ISO TS 15066, Limits for quasi-static and transient contact	Robot is capable of exceeding the limits for quasi-static and transient contact specified in ISO TS 15066, Limits for quasi-static and transient contact
2	Vertical fall	N/A – Class 2 is the minimum for this hazard	Robot mass does not exceed 1 kg[a]	Robot mass exceeds 1 kg[a]
3	Entrapment	Robot mass does not exceed 7 kg[b], robot vertical length does not exceed 1 m[c], and robot does not have a manipulator	Robot mass does not exceed 25 kg[b], robot vertical length does not exceed 1 m[c], and robot does not have a manipulator	Robot mass exceeds 25 kg[b], robot vertical length exceeds 1 m[c], or robot has a manipulator
4	Manipulation[g]	N/A – Class 2 is the minimum for this hazard	Manipulator is not capable of exerting a force in excess of 50 N on humans or other obstacles, moves at a speed not exceeding 0.25 m/s, and has a rated load not exceeding 10 kg[d][e]	Manipulator is capable of exerting a force in excess of 50 N on humans or other obstacles, moves at a speed exceeding 0.25 m/s, or has a rated load exceeding 10 kg[d][e]

[a] The 1 kg mass for vertical fall is sourced from Classification for various categories of mechanical energy sources of CSA C22.2 No. 62368-1/UL 62368-1.

[b] The 7 kg and 25 kg mass for entrapment are sourced from Classification for various categories of mechanical energy sources of CSA C22.2 No. 62368-1/UL 62368-1.

[c] The 1 m vertical length for entrapment is sourced from the representative vertical length of a toddler (3-year-old child), based on the manikin referenced in 7.2.5c), Obstacle test, child's body. Indicators that extend from the main body of the robot that do not pose an entrapment risk (e.g., flags) are not considered when determining vertical length.

[d] Force and speed parameters for manipulation shall consider simultaneous movement of the manipulator and robot's mobile platform when applicable.

[e] Manipulation thresholds are sourced from ISO 10218-1.

[f] Functions intended to limit the force of horizontal impacts, e.g., safety-limited speed, are not considered when determining Hazard Class.

[g] Manipulation hazard does not apply to robots with no manipulators and no end-effectors.

8.4 Functional safety

Safety functions as specified in 8.2, Safety functions, shall comply with one of the following functional safety standards:

– ISO 13849;

– IEC 62061;

– IEC 61508; or

– Requirements from UL 60730-1, Requirements for electronic controls, are permitted to be applied to low complexity, low risk safety-related control systems when the robot is intended for household use.

Where detection of people is necessary, the requirements in IEC/TS 62998-1 may be used in the absence of a specific safety standard for the sensing technology.

NOTE Many safety functions can use IEC/TS 62998-1, e.g., ensuring that the separation distance with the obstacle/person is maintained, critical edge detection and stopping before falling, etc.

Compliance is determined with the respective standard (i.e. ISO 13849, IEC 62061, IEC 61508, UL 60730-1, Requirements for electronic controls, IEC/TS 62998-1) and the relevant tests of Clause 7 of this Standard.

8.4.1 Functions intended for Class 1

Functions intended to address hazards of Class 1 are not required to comply with functional safety requirements.

EXAMPLE Class A control function per UL 60730-1.

8.4.2 Safety functions intended for Class 2

Safety functions intended to address hazards of Class 2 shall comply with a safety level that addresses basic safety risk. Exact safety level is to be based on risk assessment.

EXAMPLE ISO 13849-1 Performance Level b or c, IEC 61508 Safety Integrity Level 1, or Class B control function per UL 60730-1.

8.4.3 Safety functions intended for Class 3

Safety functions intended to address hazards of Class 3 are required to comply with a safety level that addresses elevated safety risk. Exact safety level is to be based on risk assessment.

EXAMPLE ISO 13849-1 Performance Level d or e, IEC 61508 Safety Integrity Level 2 or 3, or Class C control function per UL 60730-1.

8.4.4 Functions that are not safety-related

The functional safety assessment in 8.4, Functional safety, shall establish that functions that are not safety-related, e.g., a navigation function using SLAM (simultaneous localization and mapping) data, do not adversely impact safety functions.

8.4.5 Additional test cases to consider in functional safety verification and validation activities

The manufacturer shall conduct additional test cases as part of their functional safety verification and validation activities for situations not covered in Clause 7. This shall include consideration of, but are not limited to, the following:

– Testing on additional floor surfaces (see 7.2.3, Floor surfaces);

– Consideration of additional stability and loading conditions (see 7.2.4, Robot stability test);

– Consideration of additional elevation changes (see 7.2.4.1, Elevation change test) including gaps between test surfaces, e.g., for an outdoor robot, a trench between a concrete path and a lawn caused by erosion;

– Consideration of additional obstacles (see 7.2.5, Obstacle test), for example:

- – Backpacks;
- – Sports equipment, e.g.:
  - – Baseball bat, ball, skateboard/scooter;
- – Food and drink containers, e.g.:
  - – Glass cans and bottles (different tints – clear, green, brown, etc.);
- – Pets and domestic animals;
- – Caution tape;
- – Cardboard;
- – Moving objects;
- – Automated vacuums (indoor);
- – Automated lawnmower (outdoor);
- – Other robots;
- – Movable obstacles;
- – Objects that reflect or refract light;
- – Pipe/sprinkler head;
- – Wheelchair;
- – Walking cane;
- – Crutches;
- – Walker;
- – Fences (split rail, chain link, etc.); and
- – Power cable from relocatable power tap (e.g., 14-gauge SJT or equivalent flexible cable).

8.5 Protective stop

Robots shall be provided with at least one protective stop safety function. Protective stop shall be evaluated based on the robot's maximum Hazard Class determined in Table 3.

NOTE 1 The specific conditions that necessitate actuation of the protective stop are determined by risk assessment (see Clause 8.1, Risk assessment).

A protective stop shall cause all robot motion and hazardous conditions to stop or result in a safe state.

NOTE 2 Time or distance needed is dependent on the robot and application.

8.6 Collision avoidance or limitation

Robots shall be provided with one or more safety function(s) for collision avoidance or to limit the force of collision to mitigate the risk of horizontal impact. Additional directional sensing is required if deemed necessary by the risk assessment.

8.7 Critical edge detection

Robots shall be provided with one or more safety function(s) for critical edge detection to mitigate the risk of vertical fall.

8.8 Entrapment

Robots shall be provided with one or more safety functions to mitigate the risk of entrapment.

An emergency stop function used to mitigate the risk of entrapment shall comply with ISO 13850.

8.9 Safety-limited speed

Safety function(s) for safety-limited speed shall be provided when determined by risk assessment. Safety-limited speed shall be evaluated based on the robot's maximum Hazard Class determined in Table 3. The risk assessment shall be used to determine the speed limit that shall be implemented for the particular robotic application.

8.10 Manipulator movement

Safety function(s) to mitigate risk of hazardous manipulator movement shall be provided when applicable. Examples of safety functions related to manipulator movement include, but are not limited to:

– In the case of robots not intended for direct interaction with persons, stopping manipulator movement upon detection of persons near the robot's maximum space;

– In the case of robots intended for direct interaction with persons, speed- and/or force-limiting upon detection of persons;

– Detecting if the robot can safely handle objects. This includes correct identification of objects that are intended to be manipulated versus objects (including persons) that are not intended to be manipulated, which shall be clearly defined in the robot specification;

NOTE This could be based on criteria like size, weight, toxicity, sharpness, fragility etc.

– Safety functions to limit the motion of robot manipulator(s) and/or end-effector(s);

– Safety functions that maintain safe operation of the robot and the manipulator(s) during simultaneous movement, and/or preventing simultaneous movement of the manipulator and robot's mobile platform; and

– Other safety functions to prevent dropping of payloads, unintended movement, and the like that could be caused, for example, by robot instability, activation of the emergency stop, loss of drive power, incorrect end-effector orientation and/or failure to complete an intended motion.

8.11 Other safety functions

8.11.1 General

Other safety functions are required as determined by the risk assessment. Examples of other safety functions include, but are not limited to:

– Detection of the boundaries of the robot's operating space (e.g. through the use of magnetic tape, geofencing, etc.) to avoid forbidden areas; and

– Instability detection due to improper or overloading of the robot.

8.11.2 Braking

Braking shall be provided if required to meet the stopping times or distances according to safety functions and the requirements in 8.5, Protective stop – 8.10, Manipulator movement. Travel surfaces shall be defined in the robot specification, along with the robot's maximum load and speed capabilities. The robot shall not lose stability or drop loads while braking and coming to a stop.

8.11.3 Start/re-start sequence

Upon initial power-on and/or power restoration in normal operation, the robot shall not pose a risk of fire, electric shock, or personal injury. Either:

– The robot shall remain stopped until a manual action is performed by the user to start or resume robot operation; or

– The control system of the robot shall perform routine(s) to verify all safety functions are available prior to starting or resuming robot operation.

EXAMPLE Power-on self-tests of safety-related sensors, logic, and actuators; communication, power & logic checks; etc.

8.11.4 Fail safe routine

Robots shall have a defined fail-safe routine intended to maintain safe operation of the robot if a condition is detected that could compromise safety. Examples include hardware fault, loss of communications with the docking station, or battery over-discharge.

NOTE Because of the different functions that could be provided (e.g., by manipulator(s) and/or end-effector(s)), the fail-safe routine is to be defined by the manufacturer. The intent is to address potential risks of pain or injury to persons (e.g., due to unintended manipulator and/or end-effector movement, unintended dropping of loads or robot parts, and the like). Depending on the robot application, it could involve holding the manipulator(s) and/or end-effector(s) in place, placing the load down safely on a nearby surface, and/or removing power from the manipulator(s) and/or end-effector(s).

Upon completion of the fail-safe routine, the robot shall not engage in further operation until a manual action intended to reset the robot is performed by a user.

The robot's fail-safe routine shall be described in the instructions for use (see Clause 12).

8.12 Off-the-shelf (OTS) software

8.12.1 General

NOTE 1 SCIEE robots rely on software to operate safely, which likely includes some OTS software of unknown quality. This Clause defines requirements for OTS software, as the functional safety standards listed in 8.4, Functional safety, do not have consistent requirements. The requirements in this subclause are based on OTS software UL 1998, Software in programmable components.

NOTE 2 This Clause is intended to apply to portions of the software in the safety-related control systems of the robot; not to the safety-related software in its entirety.

The manufacturer shall provide evidence demonstrating that any OTS software used to comply with the requirements of Clause 8 is suitable for use in the intended safety application. This shall include, at a minimum, the information described in 8.12.2, Required information for OTS software – 8.12.6, Validation requirements.

8.12.2 Required information for OTS software

For any OTS software that interfaces with the manufacturer-supplied software, the following information shall be provided:

a) The name and version/revision identifier of the OTS software;

b) The name of the OTS software provider;

c) A description of the purpose for which the software being used, including safety requirements that are being fulfilled by the OTS software;

d) A clear description of the function(s) provided by the software;

e) An interface specification showing all the control and data flows in and out of the OTS software;

f) References to the OTS software documentation for each callable routine that interfaces with the manufacturer's software;

g) Configuration of the OTS software, including parameters, their description, and acceptable ranges; and

h) The target environment in which the OTS software is intended to be used.

8.12.3 OTS software failures

Failures of each OTS software shall be considered in the risk assessment (8.1). For OTS software providing supervisory functions, e.g., operating systems, this shall include failures of the following:

– Scheduling frequency and criticality of safety-related tasks;

– Resources utilized by safety-related tasks;

– Memory usage and addressing;

– Control of the execution of the software; and

– Partitioning.

8.12.4 Compliance with functional safety requirements

Each OTS software shall be provided with one or both of the following:

– Hardware and/or software safeguard(s) that address each OTS software failure identified in the risk assessment per 8.1, Risk assessment. These safeguards shall comply with appropriate functional safety requirements (e.g., SIL, PL, Class) for the safety function(s) described in 8.2, Safety functions.

– The OTS software complies with appropriate functional safety requirements (e.g., SIL, PL, Class) for the safety function(s) described in 8.2, Safety functions.

8.12.5 Known issues

For each OTS software, the manufacturer shall provide a list of known issues for the precise revision/version of the OTS software that the manufacturer intends to use. For each issue, evidence shall be provided that the issue does not impact safety, e.g., the issue has been fixed, or features impacted by the issue have not been used.

8.12.6 Validation requirements

For each OTS software, during the functional safety assessment in 8.4, Functional safety, the manufacturer shall provide evidence of validation of the OTS software as integrated into the safety application. This shall include:

– Demonstration of test coverage against the requirements that need to be fulfilled in the intended application, and

– Test coverage of various operating conditions including the failures identified in 8.12.3, OTS software failures, showing that those failures do not lead to a loss of one or more safety function(s) in the intended application.

8.13 Cybersecurity

A cybersecurity threat assessment shall be conducted. If the cybersecurity assessment has identified threats that could lead to safety risk(s), cybersecurity measures shall be provided to prevent unauthorized access to the robot, its hardware, software, configuration data and the application program.

NOTE 1 The means to prevent unauthorized access can include providing the following:

– ability to disable access to communications ports, e.g. TCP/UDP port;

– ability to change the TCP/UDP port number, e.g. logical connection;

– authenticated protection of the safety configuration; and

– ability to change the default configurations (e.g. usernames, user passwords, IP addresses and safety authentication).

NOTE 2 For guidance about the cybersecurity considerations for risk assessment and risk reduction, see ISO/TR 22100-4.

NOTE 3 For information about security aspects related to functional safety, see IEC TS 63074.

NOTE 4 Defining a complete approach to security is out of scope of UL 3300. However, security is a significant concern with regards to safety. These requirements are intended to assist with selecting an adequate security approach to reduce safety risk.

8.14 Remote software updates

8.14.1 General

Programmable controls having a safety function and capable of being updated from a remote, authorized entity shall comply with UL 5500.

The requirements of UL 5500 are tailored for this Standard in 8.14.2, Definition of "remote" – 8.14.9, Relevant security incidents, below:

8.14.2 Definition of "remote"

The definition of "remote" is any update not performed directly at the robot using physical media.

8.14.3 Definition of "acceptable risk"

The definition of "acceptable risk" is as determined as part of the risk assessment process in 8.1, Risk assessment.

8.14.4 Process steps

The process steps stated in UL 5500 may be discrete or combined and shall only take place while robot is in a safe state, e.g. no motion until update has successfully completed.

8.14.5 Unique identification of the end product

Unique identification of the end product as required in UL 5500 shall include manufacturer-specified means to uniquely identify the robot and each of its safety-related control systems.

8.14.6 Download/transmission

Download/transmission of the software download package as specified in UL 5500, Download/transmission, shall additionally include means to address communications errors in accordance with the corresponding Performance Level or Software Class for the safety function.

8.14.7 Verification and application

Verification and application of the received software download package's data integrity as required in UL 5500, Application of received software download package and conclusion of remote software update process, shall be in accordance with the corresponding Performance Level or Software Class for the safety function.

8.14.8 Definition of "fail-safe condition"

A fail-safe condition as referred to in UL 5500, Remote software update validation is considered to be no robot motion and no risk of fire, electric shock, or pain or injury to persons.

8.14.9 Relevant security incidents

Relevant security incidents as referred to in UL 5500, Failure/status identification detection, include those identified in the cybersecurity threat assessment in 8.13, Cybersecurity.

Compliance is checked as specified in UL 5500.

8.15 Artificial intelligence and machine learning

When artificial intelligence and machine learning is used in a safety-related function or could impact a safety-related function, it shall adhere to the requirements outlined for functional safety within 8.4, Functional safety, based on risk assessment.

NOTE At the time of development of UL 3300, existing safety standards do not address AI/machine learning in detail. However, it is expected that future editions and standards will have more details e.g. IEC 61508 or UL 4600.

8.16 Sensor configuration, calibration and servicing

Sensors of safety-related control systems shall perform within the safety parameters specified for their intended use in the robotic function application. Configuration and calibration of their safety parameters shall be according to ISO 13849 or other equivalent functional safety requirements.

When a component of a safety system is expected to be field replaced, the component shall be easily removed and replaceable without damage to the robot. Robotic functions shall not be automatically enabled after component replacement. After component replacement, the robot shall perform an automatic test to verify operation and the safety functions per manufacturer specification. This includes confirmation that the component is properly configured and calibrated. If component replacement, included any testing, requires personnel with particular knowledge or skills, said personnel shall only be used for this replacement. The procedure for replacing a component and/or the need for personnel with knowledge or skills shall be described in the instructions for use. Compliance is checked by inspection and, if necessary, test.

9 Electric Power Sources

A robot shall not pose a risk of electric shock or fire hazard while mobile or while stationary, including when charging its batteries.

Power supplies and battery chargers shall comply with CSA C22.2 No. 62368-1/UL 62368-1 or CSA C22.2 No. 60335-2-29/UL 60335-2-29. When battery charging is integral to the robot, or the battery charger has any protective features, CSA C22.2 No. 62368-1/UL 62368-1, Equipment containing batteries and their protection circuits, shall be applied.

NOTE If the robot has intended functions in addition to SCIEE, additional external power supply standards related to those functions could be applicable.

External power supplies with an accessible power cord, including those that charge a battery, shall employ the following:

– a jacketed power supply cord, minimum Type SJT, if a robot, weighing 10 kg or more, is intended to automatically return to the power supply; and

– a jacketed power supply cord, minimum Type SJT, and also marked "W" for sunlight resistance and wet location, if a robot is intended for use outdoors.

10 Indicators

10.1 General

Audible and visual indication shall be provided prior to each robot task, including those performed by manipulator(s) and end-effector(s), unless there is a supervising operator. Means to disable indicators may be provided for robots intended for household use that are assigned Hazard Class 1 for horizontal impact (see Clause 8.3, Hazard Classes for robotic mobility).

All audible and visual indicators and their meanings shall be explained in the robot's operating instructions (see Clause 12).

NOTE Audible and/or visual indication can be deemed necessary during other states of the robot per manufacturer risk assessment. Indication of robot motion should be differentiated from indication of manipulator and/or end-effector movement, unless type of movement is obvious or if not deemed necessary depending on the robot specification.

10.2 Audible indicators

Audible indicators shall have a minimum output level above the ambient noise level declared in the robot specification. The sound pattern and frequency of audible indicators shall be comparable to similar movement indicators used in the same use environment (see Annex D).

Audible indicators shall have a maximum output level not exceeding 85 dB(A).

Exception: When the robot specification includes open air environments where the typical ambient noise is greater than 85 dB(A), the minimum and maximum output levels shall be as specified in the risk assessment of 8.1, Risk assessment.

The output level of audible indicators shall be measured at a distance of 1 m, or distance as stated by manufacturer risk assessment (see 8.1, Risk assessment), from the centerline of the robot or the manipulator, as appropriate, in each possible direction of movement while the robot and manipulator are stationary. The output level shall be found to be in accordance with the minimum and maximum output levels.

Compliance is checked by inspection of the audible indicators.

10.3 Visual indicators

Visual indicators shall be readily visible at a distance of 1 m, or distance as stated by manufacturer risk assessment (see 8.1, Risk assessment), from the centerline of the robot or the manipulator, as appropriate. Visual indication may be provided by a single indicator or multiple indicators as long as the indication is visible from any location around the robot. Annex D, Indicators, provides further guidance on design of visual indicators.

Compliance is checked by inspection of the visual indicators.

11 Batteries

Batteries and cells that power mobility functions (see Clause 6) shall comply with the requirements of one of the following:

– CSA C22.2 No. 62368-1/UL 62368-1, Equipment containing batteries and their protection circuits;

– UL/ULC 2271; or

– UL/ULC 2580.

Protection circuits, e.g. battery management systems, internal to the battery shall be evaluated with the battery in accordance with the applicable requirements for protection circuits in the corresponding battery standard.

Protection circuits that are provided external to the battery shall be evaluated as part of the complete robot. Protection circuits shall be evaluated as safety-related control systems per Clause 8 and additionally shall be subjected to the environmental stress tests in 7.4, Environmental stress tests. Batteries and cells used to power a robot application e.g. display, projector, etc. shall be evaluated in accordance with CSA C22.2 No. 62368-1/UL 62368-1, Equipment containing batteries and their protection circuits. Means shall be provided to prevent risk of pain or injury to persons when the robot's batteries and cells are reaching their end-of-discharge voltage. This could include, for example, initiation of the fail-safe routine described in 8.11.4. These means shall be subjected to the test in 7.2.8, Battery discharge test.

12 Markings and Instructions

All markings and instructions identified in the non-robotic function referenced standard are applicable to the robot. They are to be provided as directed by that Standard, as a marking or instruction, when and where specified. All symbols, pictorials, audible and visual indicators shall be explained in the operating instructions. When a pictorial is used on the robot, it must be clearly understood by the intended user group.

NOTE ISO 7000, Graphical symbols for use on equipment – Index and synopsis, is generally accepted as a resource for clearly understood pictorials.

All instructions shall be in the language of the country for use. Service instructions may be in English-only, unless a specific country language is identified in the application associated Standard.

The intended users, operators and servicing persons shall be detailed in the respective manuals.

For robots that are intended to carry a payload or deliver any item, the maximum load capacity shall be marked on the robot near the area that will maintain the payload. Marking of the load capacity on the robot is not required if the robot automatically detects it can safely handle the payload, in which case the automatic detection shall be considered a safety function and evaluated in accordance with Clause 8.

Instructions shall be provided that identify the type and location of all safety-related controls and what service and maintenance is required. They shall indicate the steps to commission the robot, how to perform any diagnostics, and they shall state the substance of the following:

– WARNING Risk of personal injury. Sensors and controls shall only be serviced by a skilled person.

All service and maintenance to be conducted by instructed or skilled persons shall be clearly stated and explained in the operating instructions.

Annex A
(normative)

Textiles

Fabric used as an integral part of a robot, which also includes that worn by the robot, shall meet minimum requirements for adult apparel. Table A.1 lists the applicable testing for the textiles.

Fabric used as an integral part of a robot shall meet minimum requirements for children's apparel if the robot has features that can encourage its placement adjacent to a sleeping child.

Compliance criteria is as defined in Table A.1.

Table A.1
Textiles

Test	Scope
Textile fiber identification	Code of Federal Regulations (CFR) 16, Part 303.4 and Code of Federal Regulations (CFR) 16, Part 303.15 Citation: Textile Fiber Products Identification Act
Fiber content	AATCC 20 (2013) and AATCC 20A (2014) Citation: 16 CFR 303.43
Flammability	Code of Federal Regulations (CFR) 16, Part 1610 Fabrics that meet Class 1 Citation: Flammable Fabrics Act
Labeling and care	Code of Federal Regulations (CFR) 16, Part 423 https://www.ftc.gov/node/119456
If leather or imitation leather	15 USC 45 and Code of Federal Regulations (CFR) 16, Part 24 Imitation or simulated leather must be disclosed (e.g., non-leather, simulated leather, vinyl, vinyl coated fabric, plastic, etc.) bonded leather, ground leather, pulverized leather, shredded leather, reconstituted leather, if stated, must also include the percentage of leather fibers and non-leather substances in the material. EXAMPLE 60 % leather fiber, 40 % non-leather substances. Trade names, coined name, trademark is not allowed if it misrepresents directly or by implication that an industry product is made in whole or in part from animal skin or hide.
If organic material claim	Code of Federal Regulations (CFR) 167, Part 205.100 Any product that is sold, labeled, or represented as "100 percent organic," "organic," or "made with organic" must be USDA organic certified (for example Organic Cotton), meaning it has met the requirements of the USDA National Organic Program (NOP) standards. In order to show compliance, the supplier must submit certification.

NOTE There are multiple voluntary requirements applicable the testing of textiles used as adult apparel and equipment. Only those requirements cited as mandatory based on present practice for textiles are included above.

Annex B
(normative)

Required Information for Robot Specification

B.1 General

The manufacturer shall provide the information specified in Table B.1, Table B.2, and Table B.3.

Table B.1
ODD

Parameter	Values	Clause/Subclause
Specific allowed and disallowed locations or regions of operation for robot	Locations of operation allowed and disallowed (e.g., home, residence, school, etc.)	5 Non-robotic Function 8.1.2 Define intended use and operational limits
Location of operation	Indoor Outdoor Both	5.2.3 Environmental conditions 7.2.2 General testing requirements 7.2.3 Floor surfaces 7.2.4 Robot stability test 7.4.10 Exposure to moisture 8.4.5 Additional test cases to consider 9 Electric Power Sources CSA C22.2 No. 62368-1/UL 62368-1 or CSA C22.2 No. 60335-1/UL 60335-1 Outdoor use requirements
Wet locations allowed?	Yes No	5.2.3 Environmental conditions 7.2.4 Robot stability test 7.4.10 Exposure to moisture 9 Electric Power Sources CSA C22.2 No. 62368-1/UL 62368-1 or CSA C22.2 No. 60335-1/UL 60335-1
Dust / dirt / debris tolerance	Enclosure type or ingress protection rating	5.2.3 Environmental conditions 8.1.2 Define intended use and operational limits CSA C22.2 No. 62368-1/UL 62368-1 or CSA C22.2 No. 60335-1/UL 60335-1 Outdoor use requirements
Minimum and maximum ambient operating temperatures	Minimum temperature in degrees Celsius (°C) Maximum temperature in degrees Celsius (°C)	5.2.5.1 Touch temperature test 5.2.5.2 Temperature test in recessed installation 7.2.2 General testing requirements 7.2.11 Touch temperature test 7.4.9 Thermal cycling test CSA C22.2 No. 62368-1/UL 62368-1 or CSA C22.2 No. 60335-1/UL 60335-1 Temperature requirements
Table-top or floor-operating robot?	Table-top robot Floor-operating robot	5.3.1 Drop test 7.3.4 Drop test 7.4 Environmental stress tests
Robot intended to be carried?	Yes No	5.3.1 Drop test 7.3.4 Drop test
Minimum and maximum ambient lighting conditions	Minimum (specified in lux) Maximum (specified in lux)	7.2.2 General testing requirements 7.2.9 Light conditions test
Expected and prohibited objects	Lists of expected and prohibited objects	7.2.2 General testing requirements 7.2.5 Obstacle test 7.6 Additional evaluation of compliance 8.1.2 Define intended use and operational limits 8.4.5 Additional test cases to consider in functional safety verification and validation activities 8.6 Collision avoidance or limitation 8.10 Manipulator movement 8.11 Other safety functions
Types of flooring / operating surfaces allowed and prohibited	Wood, laminate, vinyl, tile, reflective tile, concrete, asphalt, gravel,	7.2.3 Floor surfaces 7.2.4.1 Elevation change test 7.2.6 Vibration test

Table B.1 Continued on Next Page

Table B.1 Continued

Parameter	Values	Clause/Subclause
	carpet, rubber mat, lawn, turf, dirt, sand, other	7.3.4 Drop test 8.4.5 Additional test cases to consider in functional safety verification and validation activities 8.11.2 Braking
Slopes or elevation changes allowed?	Yes No Maximum slope/elevation change permitted	7.2.4 Robot stability test 7.2.4.1 Elevation change test 8.4.5 Additional test cases to consider in functional safety verification and validation activities
Who will be around the robot?	List of persons expected to be around the robot (ordinary persons, vulnerable persons, age groups, employees, etc.)	8.1.2 Define intended use and operational limits
Minimum and maximum ambient noise levels	Minimum, specified in dB(A) Maximum, specified in dB(A)	10.2 Audible indicators

Table B.2
Robot Characteristics

Parameter	Values	Clause/Subclause
Non-robotic function standard applied	CSA C22.2 No. 62368-1/UL 62368-1 CSA C22.2 No. 60335-1/UL 60335-1 (plus any applicable Part 2s)	5 Non-robotic Function 6 Mobility 7 Testing 9 Electric Power Sources 11 Batteries 12 Markings and Instructions Annex C Use of CSA C22.2 No. 60335-1/UL 60335-1, Alternative General Requirements
Power source, power supplies, and battery chargers	Description, including ratings in volts (V), amperes (A)	5 Non-robotic Function 7.4 Environmental stress tests 9 Electric Power Sources CSA C22.2 No. 62368-1/UL 62368-1 or CSA C22.2 No. 60335-1/UL 60335-1 power supply requirements
Type of battery charger: internal/external, docking station, etc.	Internal External Docking station	5 Non-robotic Function 7.2.4 Robot stability test 7.3.3 Enclosed compartment test 9 Electric Power Sources
Type of battery charging – Wireless or wired	Wireless Wired	5 Non-robotic Function 9 Electric Power Sources
Amount of power transferred during charging	Ratings in volts (V), amperes (A), and/or watts (W)	5 Non-robotic Function 9 Electric Power Sources
Charger / docking station location (if applicable)	N/A Not specified Specific location Recessed location	5.2.5.2 Temperature test in recessed location
Battery ratings	Ratings in volts (V), amperes (A), degrees Celsius (°C)	5 Non-robotic Function 7.2.8 Battery discharge test 7.4 Environmental stress tests 8 Safety-related Control Systems 9 Electric Power Sources 11 Batteries CSA C22.2 No. 62368-1/UL 62368-1 or CSA C22.2 No. 60335-1/UL 60335-1 Battery requirements
Minimum and maximum charging and discharging temperatures	Temperatures in degrees Celsius (°C)	7.2.2 General testing requirements 7.2.8 Battery discharge test 8 Safety-related Control Systems 11 Batteries CSA C22.2 No. 62368-1/UL 62368-1 or CSA C22.2 No. 60335-1/UL 60335-1 Temperature requirements

Table B.2 Continued on Next Page

Table B.2 Continued

Parameter	Values	Clause/Subclause
Is the battery swappable?	Yes No	5 Non-robotic Function 9 Electric Power Sources
Are there external connections or cords?	Yes No	9 Electric Power Sources CSA C22.2 No. 62368-1/UL 62368-1 or CSA C22.2 No. 60335-1/UL 60335-1 power supply cord requirements
Materials of robot's accessible surfaces	Metal Ceramic Glass Wood Plastic Textiles Hazardous materials Heavy elements Other	5.1.4 Toxicology 5.1.5 Textiles 5.2.4 Sharp edges 5.2.5.1 Touch temperature test 7.2.11 Touch temperature test Annex A, Textiles
Are there detachable robot parts? If so, what are their sizes?	Yes No Size of robot parts	5.2.2 Size of parts 7.2.2 General testing requirements 7.2.13 Access to small parts testing 7.3 Safeguards provided for robot shape and size
Audible and visual indicators and warnings	List of all audible and visual indicators and warnings	6.1 Indicators 10 Indicators 12 Markings and Instructions
Location of electrical power disconnect	Power disconnect location	6.2 Robot stop control
Robot method of movement	Wheeled / rolling Legged Other	6.3 Manipulators 7.2.6 Vibration test 7.3.4 Drop test 7.5 Tests for robots with manipulators (all)
Does robot have manipulators and/or end-effectors?	Yes No	6.3 Manipulators 7.2.2 General testing requirements 7.2.6 Vibration test 7.5 Tests for robots with manipulators 8 Safety-related Control Systems 8.3 Hazard Classes for robotic mobility 8.10 Manipulator movement 10 Indicators
Operating space requirements (e.g., range of movement, maximum space of manipulators and/or end-effectors, distance to persons, distance to objects.)	Dimensions, distances, and diagrams explaining the robot's operating space	8 Safety-related Control Systems 8.1.2 Define intended use and operational limits
Method to limit range of motion (applicable to manipulators, end-effectors, and legged robots)	Mechanical hard stop Safety function Other	6.3.2 Range of motion 7.5.2 Mechanical hardstop test 8 Safety-related Control Systems
Type of end-effector(s), if applicable	N/A Gripper Other	6.3.3 Gripper end-effectors 7.5.4 Gripper release test
Robot vertical length	Vertical length in meters (m)	7.2.2 General testing requirements 7.2.7 Mass and vertical length measurement 8.3 Hazard Classes for robotic mobility
Robot maximum speed, including manipulators and/or end-effectors	Speed in meters per second (m/s)	7.2.2 General testing requirements 8.3 Hazard Classes for robotic mobility 8.9 Safety-limited speed 8.10 Manipulator movement 8.11.2 Braking
Robot mass (no-load)	Mass in kilograms (kg)	7.2.2 General testing requirements 7.2.7 Mass and vertical length measurement 8.3 Hazard Classes for robotic mobility
Robot maximum payload (if applicable), including of individual	Mass in kilograms (kg)	7.2.2 General testing requirements 8.3 Hazard Classes for robotic mobility

Table B.2 Continued on Next Page

Table B.2 Continued

Parameter	Values	Clause/Subclause
shelves, compartments, manipulators, and/or end-effectors		8.10 Manipulator movement 8.11 Other safety functions 12 Markings and Instructions
What kind of objects can the robot carry?	List of objects the robot can carry	7.2.2 General testing requirements 8.1.2 Define intended use and operational limits 8.10 Manipulator movement 8.11 Other safety functions
Safety-related sensors	List of safety-related sensors	7.2.2 General testing requirements 8 Safety-related Control Systems 8.11.3 Start/re-start sequence 8.16 Sensor configuration, calibration, and servicing 12 Markings and Instructions
Sensor limitations (e.g., visibility, blind spots)	List of sensor limitations	7.2.2 General testing requirements 8 Safety-related Control Systems 8.1.2 Define intended use and operational limits
Sensor configuration	Configuration specification, instructions	8.1.2 Define intended use and operational limits 8.16 Sensor configuration, calibration, and servicing 12 Markings and Instructions
Sensor calibration	Calibration specification, instructions	8.1.2 Define intended use and operational limits 8.16 Sensor configuration, calibration, and servicing 12 Markings and Instructions
Intended life limit / servicing of the robot including relevant components and parts that wear	Declaration of intended life-span and service intervals for robot and its components	8.1.2 Define intended use and operational limits 8.11 Other safety functions 12 Markings and Instructions
Safety-related control systems	List of safety-related control systems	7.2.2 General testing requirements 7.3 Safeguards provided for robot shape and size 8 Safety-related Control Systems 8.11.3 Start/re-start sequence
Safety-related actuators	List of safety-related actuators	7.2.2 General testing requirements 7.3 Safeguards provided for robot shape and size 8 Safety-related Control Systems 8.11.3 Start/re-start sequence
Method of braking	N/A Mechanical Electrical Other	7.2.15 Motor brake test 8.11.2 Braking
Are there robot surfaces that could be used as a step, stair, or seat?	Yes No Dimensions of surface in meters (m)	7.3.1 Downward force test CSA C22.2 No. 62368-1/UL 62368-1 Downward force test
Does robot have enclosed compartments? If so, what is the size?	Yes No Size of compartment	7.3.3 Enclosed compartment test
Functional safety standard applied	ISO 13849 IEC 62061 IEC 61508 UL 60730-1 Annex H IEC/TS 62998-1	8.4 Functional safety
Hazard Classes for robotic mobility: – Horizontal impact – Vertical fall – Entrapment – Manipulation	Class 1 Class 2 Class 3	8 Safety-related Control Systems
Safety functions needed to mitigate hazardous: – Horizontal impact – Vertical fall – Entrapment – Manipulation – Other hazards	List of safety functions; safety requirements specifications including required safety ratings (PL, SIL, etc.)	8 Safety-related Control Systems

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