Designation: E2853/E2853M – 22

Standard Test Method for Evaluating Ground Response Robot Capabilities: Search Tasks[1]

This standard is issued under the fixed designation E2853/E2853M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

INTRODUCTION

The robotics community needs ways to measure whether a particular robot is capable of performing specific missions in complex, unstructured, and often hazardous environments. These missions require various combinations of elemental robot capabilities. Each capability can be represented as a test method, with an associated apparatus, to provide tangible challenges for various mission requirements and performance metrics to communicate results. These test methods can then be combined and sequenced to evaluate essential robot capabilities and remote operator proficiencies necessary to successfully perform intended missions.

The ASTM International Standards Committee on Homeland Security Applications (E54) specifies these standard test methods to facilitate comparisons across different testing locations and dates for diverse robot sizes and configurations. These standards support robot researchers, manufacturers, and user organizations in different ways. Researchers use the standards to understand mission requirements, encourage innovation, and demonstrate break-through capabilities. Manufacturers use the standards to evaluate design decisions, integrate emerging technologies, and harden systems. Emergency responders and soldiers use them to guide purchasing decisions, align deployment expectations, and focus training with standard measures of operator proficiency. Associated usage guides describe how these standards can be applied to support various objectives.

Several suites of standards address these elemental capabilities including maneuvering, mobility, dexterity, sensing, energy, communications, durability, proficiency, autonomy, and logistics. This standard is part of the Human-System Interaction (HSI) suite of test methods.

1. Scope

1.1 This test method is intended for remotely operated ground robots operating in complex, unstructured, and often hazardous environments. It specifies the apparatuses, procedures, and performance metrics necessary to measure the capability of a robot to maneuver and search throughout an environment to inspect objects of interest while negotiating complex terrain. This test method is one of several related human-system interaction tests that can be used to evaluate overall system capabilities.

1.2 The robotic system typically includes a remote operator in control of all functionality, so an onboard camera and remote operator display are typically required. Assistive features or autonomous behaviors may improve the effectiveness or efficiency of the overall system.

1.3 Different user communities can set their own thresholds of acceptable performance within this test method for various mission requirements.

1.4 *Performing Location*—This test method may be performed anywhere the specified apparatuses and environmental conditions can be implemented.

1.5 *Units*—The International System of Units (a.k.a. SI Units) and U.S. Customary Units (a.k.a. Imperial Units) are used throughout this test method. They are not mathematical conversions. Rather, they are approximate equivalents in each system of units to enable use of readily available materials in different countries. The differences between the stated dimensions in each system of units are insignificant for the purposes of comparing test method results, so each system of units is separately considered standard within this test method.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the*

[1] This test method is under the jurisdiction of ASTM Committee E54 on Homeland Security Applications and is the direct responsibility of Subcommittee E54.09 on Response Robots.

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responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.

1.7 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C33/C33M Specification for Concrete Aggregates
C144 Specification for Aggregate for Masonry Mortar
E2521 Terminology for Evaluating Response Robot Capabilities
E2566 Test Method for Evaluating Response Robot Sensing: Visual Acuity
E2592 Practice for Evaluating Response Robot Capabilities: Logistics: Packaging for Urban Search and Rescue Task Force Equipment Caches
E2826/E2826M Test Method for Evaluating Response Robot Mobility Using Continuous Pitch/Roll Ramp Terrains
E2827/E2827M Test Method for Evaluating Response Robot Mobility Using Crossing Pitch/Roll Ramp Terrains
E2828/E2828M Test Method for Evaluating Response Robot Mobility Using Symmetric Stepfields Terrains
E2991/E2991M Test Method for Evaluating Response Robot Mobility: Traverse Gravel Terrain
E2992/E2992M Test Method for Evaluating Response Robot Mobility: Traverse Sand Terrain
E3349/E3349M Test Method for Evaluating Ground Robot Capabilities and Remote Operator Proficiency: Terrains: K-Rails

3. Terminology

3.1 *Definitions*—The following terms are used in this test method and are defined in Terminology E2521: *abstain, administrator or test administrator, emergency response robot or response robot, fault condition, operator, operator station, remote control, repetition, robot, stepfield terrain element, teleoperation, test event or event, test form, test sponsor, test suite, testing target or target, testing task or task,* and *trial or test trial*.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *alcove, n*—an area measuring 1W by 1W with walls on three sides, used in the rectangular labyrinth and freeform maze test configurations; see Fig. 1.

3.2.2 *apparatus clearance width (W), n*—a specification for the apparatus dimensions chosen from one of four possible measurements, based on the intended robot deployment environment:

240 cm ± 2.5 cm tolerance [96 in. ± 1 in. tolerance], such as open and outdoor public spaces;

120 cm ± 2.5 cm tolerance [48 in. ± 1 in. tolerance], such as indoor spaces in accessibility-compliant buildings;

60 cm ± 1.3 cm tolerance [24 in. ± 0.5 in. tolerance], residences and aisles of public transportation; or

30 cm ± 1.3 cm tolerance [12 in. ± 0.5 in. tolerance], cluttered indoor spaces, ductwork, and voids in collapsed structures.

3.2.2.1 *Discussion*—The measures for these scales are nominal and do not represent the measurement of the narrowest point in the apparatus through which the robot should pass. Consult Section 6 for the overall measurements and dimensions of the apparatus at each scale.

3.2.3 *hallway, n*—an area measuring 1W width by variable length which connects rooms and alcoves, used in the rectangular labyrinth and freeform maze test configurations; see Fig. 1.

3.2.4 *Landolt Ring or Landolt C, n*—an optotype, or symbol, consisting of a black circular ring with a white gap or vice versa, both with specified sizes, as defined in Test Method E2566.

3.2.5 *linear inspection rail, n*—a series of black and white buckets or PVC pipes with visual acuity targets, arranged at specified angles and attached to a 0.75W long length of wood, plastic, or metal, as shown in Fig. 2; see Section 6 for more information.

3.2.6 *quarter-ramp terrain element, n*—inclined surface of 15° that, when projected onto the ground plane, results in a footprint that is a square with each side equal to half of W.

3.2.7 *room, n*—an area measuring 2W by 2W, used in the rectangular labyrinth and freeform maze test configurations; see Fig. 1.

3.2.8 *stepfield terrain element, n*—discontinuous terrain type completely formed using an array of wood posts standing on end with nominal dimensions of 10 by 10 cm [4- by 4-in.] for the cross-section and elevations of 10, 20, 30, 40, and 50 cm [4, 8, 12, 16, and 20 in.]; the posts may be arranged to form specified topologies.

3.2.8.1 *Discussion*—This is the same definition as in Terminology E2521 – 16. This definition refers to the dimensions of the stepfield terrain elements when W = 120 cm [96 in.].

3.2.9 *visual acuity target, n*—a printed graphic of nested Landolt C symbols of varying sizes and orientations; the orientation of each C is defined by the direction of the gap in the ring out from the center.

3.2.9.1 *Discussion*—This is the same type of artifact used in Test Method E2566 – 17a. See Fig. 3.

4. Summary of Test Method

4.1 This test method is performed by a remote operator who cannot see or hear the robot within the test apparatus. The robot traverses through a defined area over terrain of varying complexity, searching for visual acuity targets positioned at various heights and orientations throughout the area, and inspecting and identifying as many of them as possible. The visual acuity targets are positioned in a set of four on a linear

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

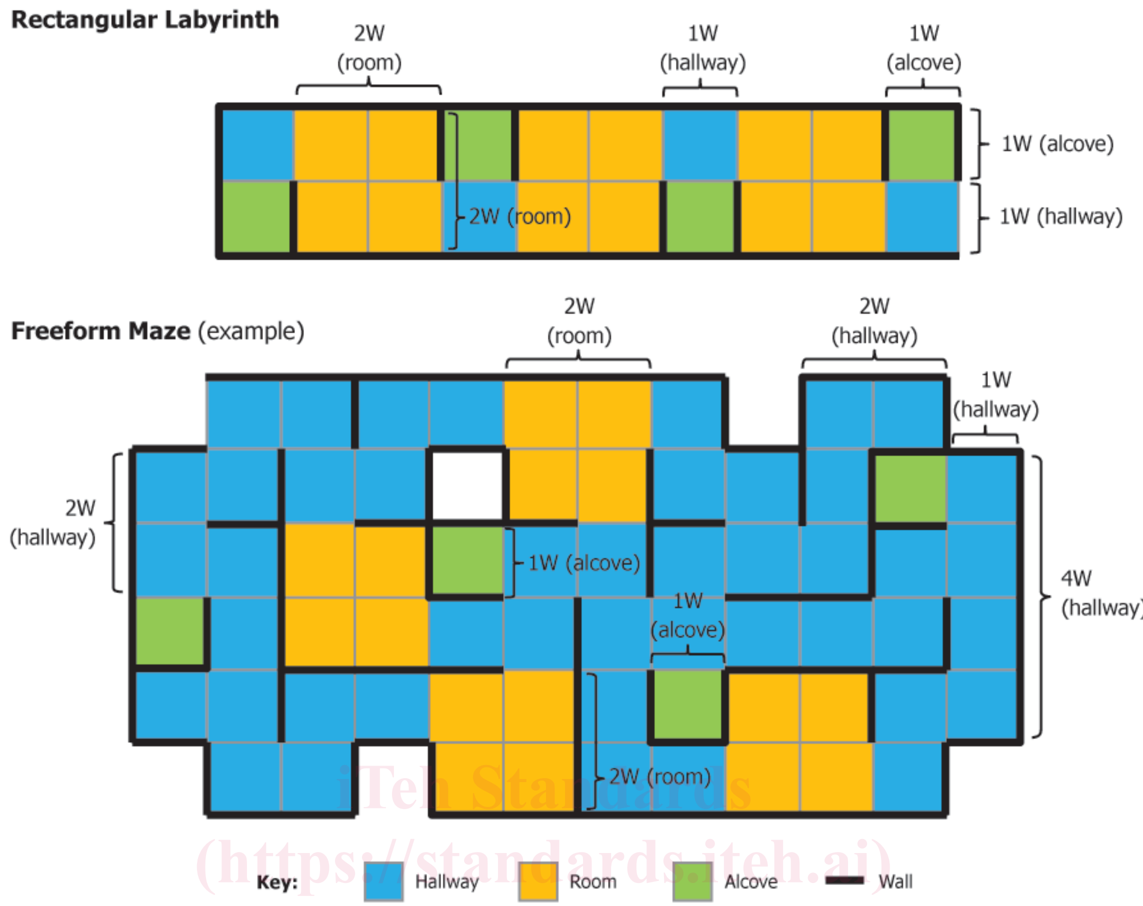

FIG. 1 Layout and Measurements of Rooms, Hallways, and Alcoves in the Rectangular Labyrinth Test Configuration and an Example of a Layout in the Freeform Maze Test Configuration

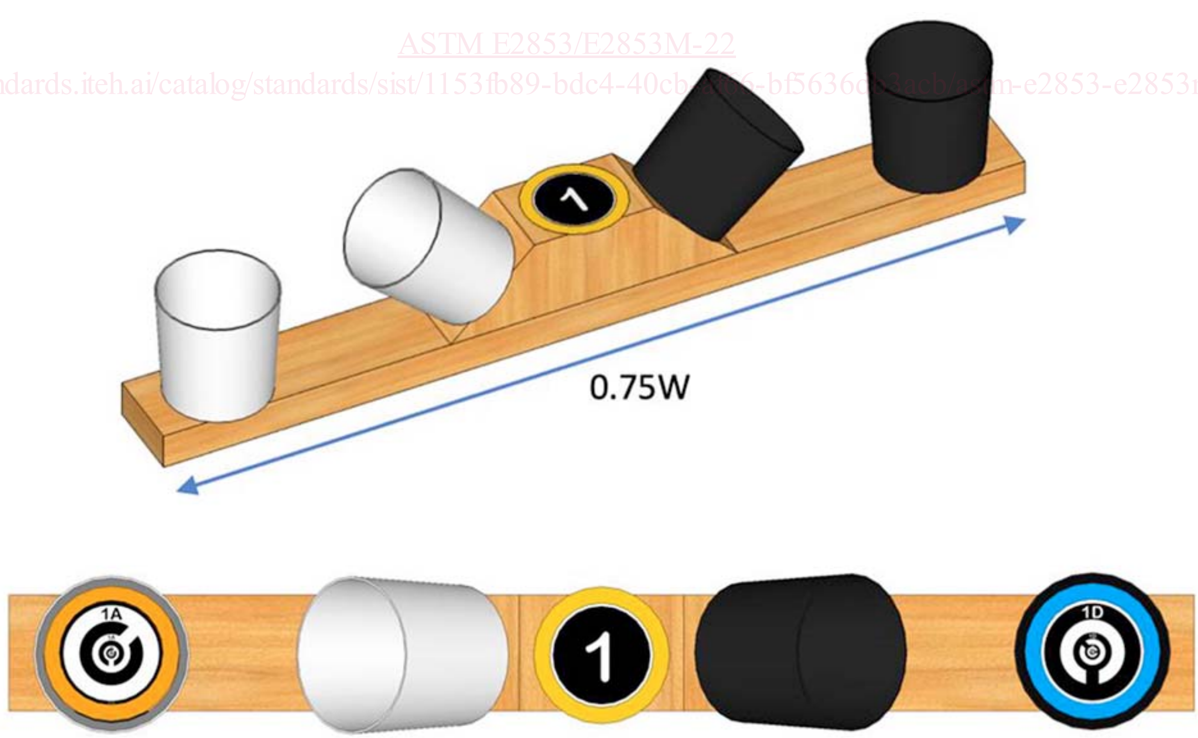

FIG. 2 Example Linear Inspection Rail Apparatus shown at an Angle (top) and from Overhead (bottom)

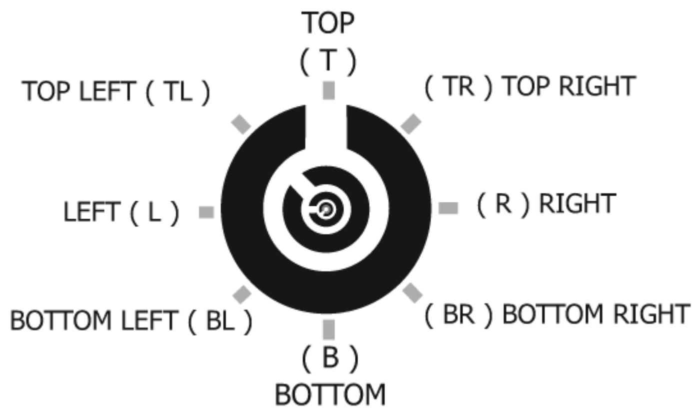

FIG. 3 Example Visual Acuity Target and the Corresponding Ring Gap Orientations

inspection rail, with a numeric label in the center as shown in Fig. 2. Ten or more linear inspection rails (depending on the test configuration) are located throughout the test apparatus for a total of at least forty visual acuity targets. Three test configurations are defined (see Fig. 4):

4.1.1 *Rectangular Labyrinth*—The robot traverses through a fabricated apparatus of a specified design. This consists of four hallways, three rooms, and four alcoves. There are pre-defined locations that are known to the operator for one set of ten linear inspection rails throughout the labyrinth. The robot navigates following either the left- or right-hand prescribed traversal path through the apparatus (see Fig. 5), which is similar to performing a left or right hand wall follow.

4.1.2 *Freeform Maze*—The robot traverses through a fabricated maze apparatus approximately two to four times the size of the rectangular labyrinth. This maze has multiple routes and intersections of a variable design (not specified) that consists of at least four hallways, three rooms, and four alcoves. It also has variable locations for one or more sets of ten linear inspection rails throughout (not pre-defined and not known to the operator), but following the prescribed heights and orientations for the linear inspection rails as defined (see 4.4). The design of the maze layout and the locations of the linear inspection rails is to be determined by the test sponsor, while following the selected apparatus clearance width (W) and minimum wall height (H) measurements (see 6.3). Multiple sets of ten linear inspection rails can be used if desired. Robot navigation through the apparatus is unrestricted, meaning there is no prescribed traversal path for the robot.

4.1.3 *Embedded Scenario*—The robot traverses through a real-world environment with multiple hallways and rooms (for example, a residential or office building) or a large open space (for example, a gymnasium). The environment is approximately two to four times the size of the rectangular labyrinth with variable locations for one or more sets of ten linear inspection rails throughout (not pre-defined and not known to the operator), to be determined by the test sponsor. Multiple sets of ten linear inspection rails can be used if desired. Robot navigation through the environment is unrestricted meaning there is no prescribed traversal path for the robot.

4.2 See Fig. 5 and Table 1 for a comparison of test configurations.

4.3 Based on the selected apparatus clearance width (W), minimum wall height (H) is also determined. The ratio of W:H is defined in order to match an intended deployment environment. For example, a typical indoor environment with hallways and rooms is defined as W = 120 cm [48 in.] and H = 240 cm [96 in.], or 1:2 ratio; a public transportation environment (for example, bus, airplane) with narrow aisles is defined as W = 60 cm [24 in.] and H = 180 cm [72 in.], or 1:3 ratio. Using these variables, seven different apparatus dimensional settings are defined; see Section 6 and Table 3 for more details.

4.4 The four visual acuity targets on each linear inspection rail are mounted recessed inside of buckets or pipes (see Fig. 2 and Fig. 3) such that they are only viewable by the robot when its camera is approximately aligned/centered with the target. The numeric label in the center of the linear inspection rail is used to identify which linear inspection rail is being inspected during the test. The dimensions of the visual acuity targets, the buckets or pipes they are mounted in, and the rail they are attached to scale depending on the apparatus clearance width (W). Each linear inspection rail is positioned in the apparatus according to a set of predefined heights that are dependent on the minimum wall height (H) (ground level, 0.25H, 0.5H, 0.75H, or H) and orientations (viewable from the front, below, or above). Additional detail is provided in Section 6.

4.5 To perform the inspection task on a linear inspection rail, the operator shall first use the robot's camera to identify the number label in the center of the linear inspection rail (for example, 1, 2, 3). Then they shall proceed to inspect the visual acuity targets that are viewable by the robot's camera, moving the robot and manipulators if necessary. Some targets may not be able to be inspected due to limitations on the robot's capability such as its camera resolution, reach of its inspection camera, or its manipulator degrees of freedom. To successfully inspect a visual acuity target, the operator must first be able to see the entire black or white ring inside of the colored ring (outside of the Landolt Cs) on the OCU display of the robot's camera (see Fig. 6 for examples of correct and incorrect alignment). The operator then must correctly discern the orientation of the gap in the Landolt Cs relative to the top of the target (marked by a number/letter), for example, top, top-right, bottom, etc., doing so down to the smallest Landolt C that they

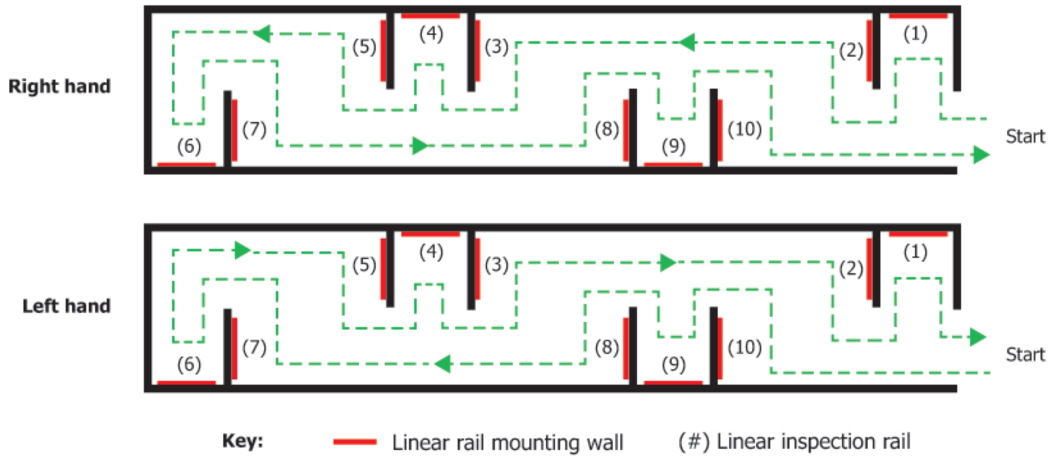

FIG. 4 The Left-Hand (top) or Right-Hand (bottom) Prescribed Traversal Path Followed by the Robot when Performing the Rectangular Labyrinth Test Configuration

are able to. Three sizes of visual acuity targets (V) are available, identified by the diameter of the outer edge of the black or white ring (inside of the colored ring): 8.3 cm [3.25 in.], 4 cm [1.5 in.], and 2.1 cm [0.8 in.]. The corresponding levels of acuity for the available Landolt C symbols for each target size are shown in Table 2. The Landolt C symbols are labeled C1 (largest) through C5 (smallest); note that the corresponding acuity for some Landolt C symbols are marked as "N/A" due to limitations in printing the 4 cm [1.5 in.] and 2.1 cm [0.8 in.] targets, which prevent some of the smallest Landolt Cs from being printed legibly. The orientations observed by the operator shall be compared to an answer key after the test is complete in order to determine the level of acuity achieved.

4.6 Terrain can vary in each test configuration. For the embedded scenario, the terrain that already exists in the environment can be used (for example, carpet, concrete). For the rectangular labyrinth and freeform maze test configurations, several terrains are specified below that can be used, many of which are referenced from other standards (see Fig. 7): flat flooring, k-rails, continuous ramps, crossing ramps, symmetric stepfields, sand, and gravel. For the rectangular labyrinth, the terrain used must be consistent throughout the entire apparatus. For the freeform maze, the terrain used can vary throughout the apparatus.

4.7 When using the rectangular labyrinth test configuration, the operator shall perform the test twice: once while navigating through the apparatus following the left-hand prescribed traversal path and again using a right-hand prescribed traversal path (see Fig. 4). Between the two navigation types, the linear inspection rails shall be inspected either in sequential order (right-hand, 1 to 10) or reverse order (left-hand, 10 to 1) as noted by the numbered label in the center of each linear inspection rail. The four targets on any given linear inspection rail may be inspected in any order. If any or all targets of a linear inspection rail are not able to be inspected by the robot and operator (for example, too high, not enough degrees of freedom in the robot's manipulator to reach, or not within the ability of the operator to control the robot to do so), then the operator may elect to skip those targets or that rail, moving to the next one in the prescribed order. They may not return to a partially completed rail, nor may they inspect the linear inspection rails out of the prescribed order. Doing so renders the test invalid. When using the freeform maze and embedded scenario test configurations, the operator's navigation is unrestricted and does not follow a prescribed path, meaning linear inspection rails can be inspected in any order.

4.8 Metrics include (in order of priority): completeness (number of visual acuity targets inspected), acuity (visual acuity level achieved per inspected target), time (time to complete the test), and return to start (if the robot returned to the start point at the end of the test).

4.9 Test completeness is defined in the rectangular labyrinth test configuration as when the operator determines that they have inspected all linear inspection rail targets possible (for example, if the robot is not able to physically reach a high target, then it may not be possible to inspect that target) and returns to the start point in the apparatus. The test may also end prematurely if the maximum test time (set by the test sponsor) is exceeded. For the freeform maze and embedded scenario test configurations, the test is completed either *(1)* when the operator declares that they believe they have found and inspected all linear inspection rail targets in the environment, *(2)* when the operator returns to the start point in the apparatus and declares that they believe they have found and inspected all linear inspection rail targets in the environment, or *(3)* the maximum test time (as set by the test sponsor) is exceeded. Setting a maximum test time as criteria for a successful test in the rectangular labyrinth, freeform maze, or embedded scenario test configurations is optional.

4.10 Potential faults include:

4.10.1 Any contact by the robot with the apparatus that requires adjustment or repair to return the apparatus to the initial condition. If a linear inspection rail or the visual acuity targets on the rail, or both, are moved or damaged significantly by the robot during testing, those targets can no longer be inspected and a fault is noted on the report form. If part of the

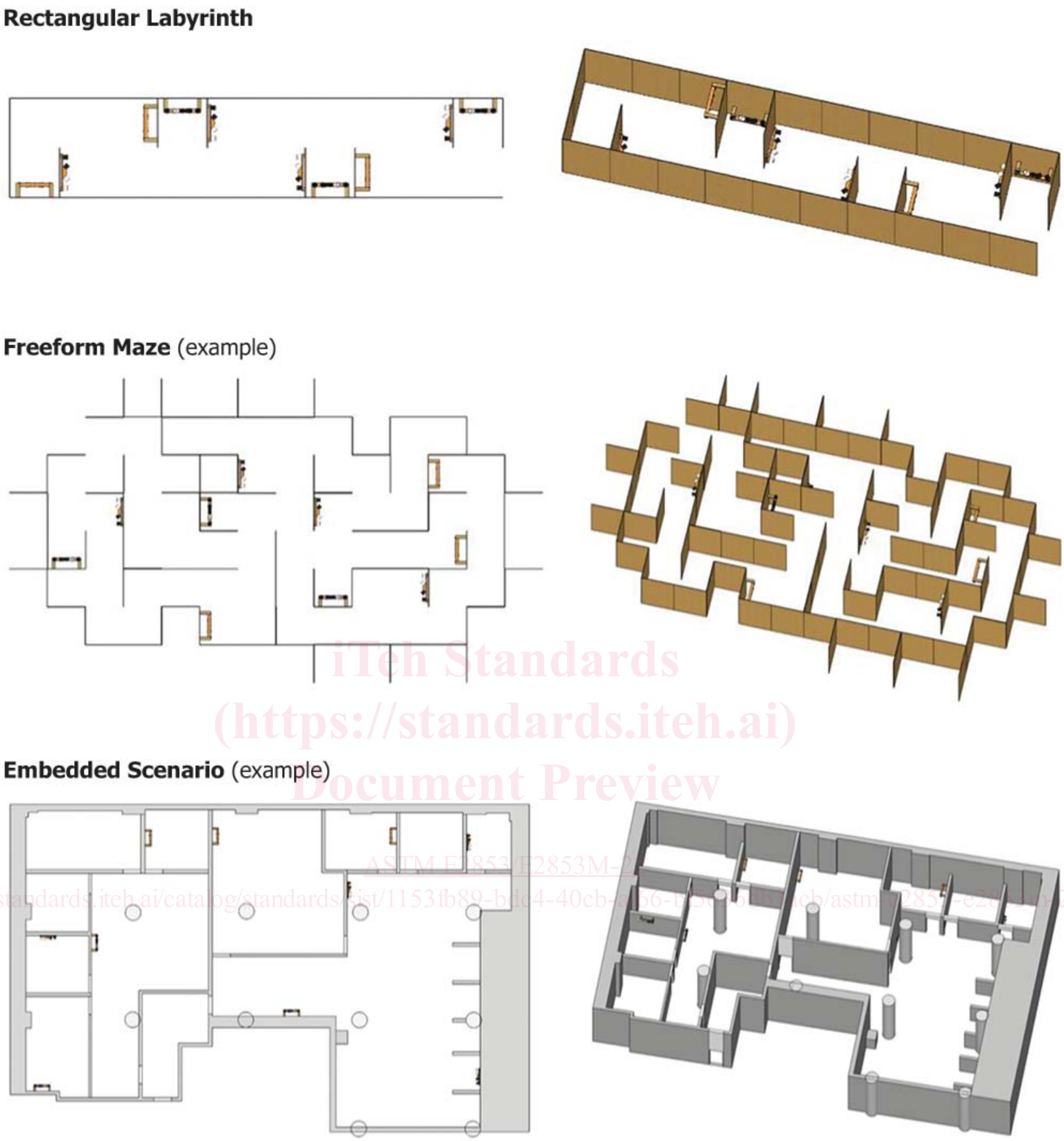

FIG. 5 Search Test Configurations, Shown Without Terrain

apparatus (for example, walls, terrain) is moved or damaged significantly by the robot during testing, the operator will be instructed to pause robot operation while the test administrator repairs the apparatus and notes the fault on the report form. The test timer will also be paused until the repairs have been made. If necessary, the robot shall be extracted from the test apparatus in order for the repair to be made, and then returned to the position where the fault occurred to continue testing.

4.10.2 Any visual, audible, or physical interaction that assists either the robot or the remote operator. For example, if the robot has a failure that would require it to be manually reset (for example, if the robot's tracks fall off, then the operator would have to enter the test apparatus to repair them), this would constitute a fault. However, if the robot has a failure that can be repaired while the operator remains remote (for example, if the robot's software has to be reset and this can be performed without the operator entering the test apparatus), this would not constitute a fault.

5. Significance and Use

5.1 This test method is part of an overall suite of related test methods that provide repeatable measures of human-system interaction capability including robotic system mobility,

TABLE 1 Search Test Configurations Summary

Settings	Rectangular Labyrinth	Freeform Maze	Embedded Scenario
Apparatus	Fabricated apparatus of a prescribed design with four hallways, three rooms, four alcoves	Fabricated maze apparatus (two to four times larger than rectangular labyrinth) with four or more hallways, three or more rooms, four or more alcoves	Real world environment (two to four times larger than rectangular labyrinth); residential, industrial, etc.
Number of linear inspection rails	One set of 10 for a total of 40 visual acuity targets	One or more sets of 10 with 40 visual acuity targets per set	
Locations of linear inspection rails	Prescribed	Variable	
Heights and orientations of linear inspection rails	Prescribed per set of 10 linear inspection rails: Four viewable from the front at ground level, 0.25H, 0.5H, and 0.75H high Three viewable from above at ground level, 0.25H, and 0.5H high Three viewable from below at 0.5H, 0.75H, and H high		Same as rectangular labyrinth and freeform maze with ±0.125H allowed variance for each height in order to fit within what is available in the scenario
Terrain	Homogeneous terrain throughout Terrain options: flat flooring, k-rails, continuous ramps, crossing ramps, stepfields, sand, gravel		Existing scenario terrain (for example, carpet, concrete)
Route(s)	Single route to dead end and back	Multiple routes via intersections for navigation choices	
Navigation	Left- or right-hand prescribed traversal path	Unrestricted; there is no prescribed traversal path for the robot	
Metrics	Completeness, acuity, time	Completeness, acuity, time, return to start	

FIG. 6 Correct Alignment is Defined as When the Operator is Able to See the Entire Black or White Outer Ring Outside of the Landolt Cs (Inside of the Colored Ring), as shown in the Left and Middle Images

TABLE 2 Levels of Acuity Achievable for Each Target Size[A]

Landolt C	Visual Acuity Target Size (V)		
	8.3 cm [3.25 in.]	4 cm [1.5 in.]	2.1 cm [0.8 in.]
C1	10.3 mm [0.4 in.]	5.0 mm [0.2 in.]	2.6 mm [0.1 in.]
C2	4.1 mm [0.16 in.]	2.0 mm [0.08 in.]	1.0 mm [0.04 in.]
C3	1.6 mm [0.06 in.]	0.8 mm [0.03 in.]	0.4 mm [0.02 in.]
C4	0.7 mm [0.03 in.]	0.3 mm [0.01 in.]	N/A
C5	0.3 mm [0.01 in.]	N/A	N/A

[A] N ⁄A indicates Landolt Cs that cannot be printed legibly, meaning they cannot be inspected.

dexterity, inspection, remote operator proficiency, and situational awareness. In particular, the operator control unit (OCU) design and interface features may impact the operator's ability to perform movement and inspection tasks with the robot.

5.2 The test apparatuses are low cost and easy to fabricate so they can be widely replicated. The procedure is also simple to conduct. This eases comparisons across various testing locations, dates, and times to determine best-in-class systems and operators.

5.3 *Evaluation*—This test method can be used in a controlled environment to measure baseline capabilities. It can also be embedded into operational training scenarios to measure degradation due to uncontrolled variables in lighting, weather, radio communications, GPS accuracy, etc.

5.4 *Procurement*—This test method can be used to identify inherent capability trade-offs in systems, make informed purchasing decisions, and verify performance during acceptance testing. This aligns requirement specifications and user expectations with existing capability limits.

5.5 *Training*—This test method can be used to focus operator training, as a repeatable practice task or as an embedded task within training scenarios. The resulting measures of remote operator proficiency enable tracking of perishable skills over time, along with comparisons of performance across squads, regions, or national averages.

5.6 *Innovation*—This test method can be used to inspire technical innovation, demonstrate break-through capabilities, and measure the reliability of systems performing specific tasks within an overall mission sequence. Combining or sequencing

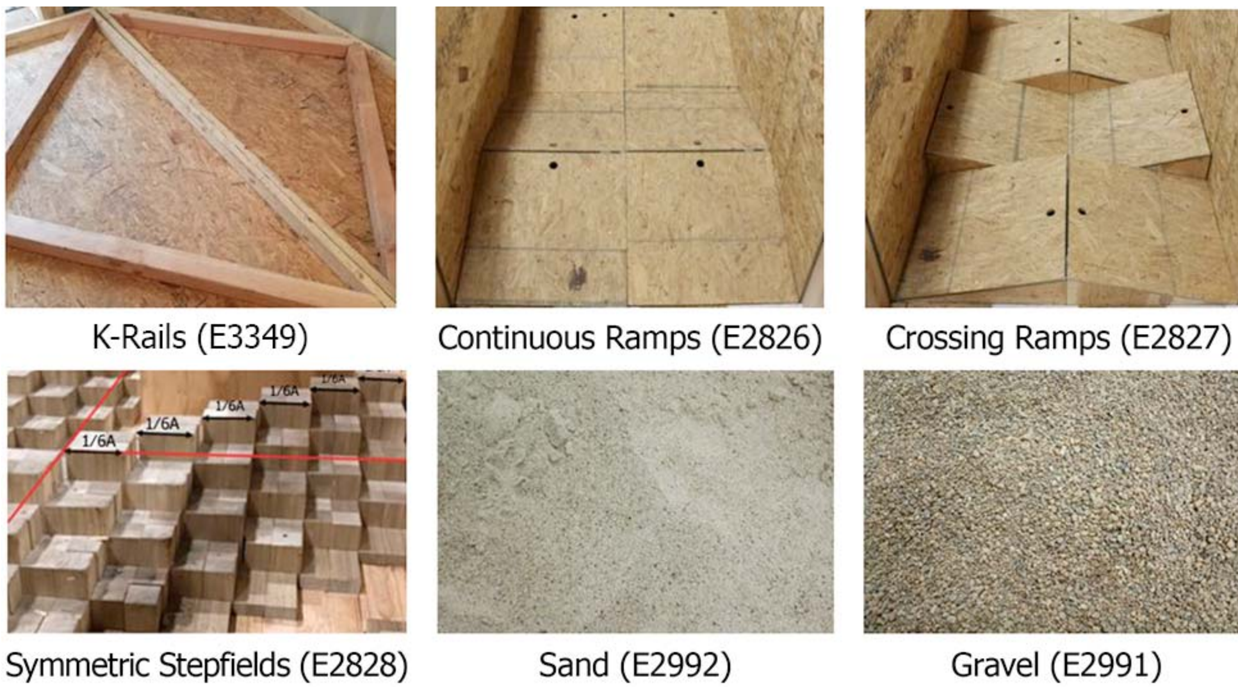

FIG. 7 Terrains that can be Utilized in the Rectangular Labyrinth and Freeform Maze Test Configurations

multiple test methods can guide manufacturers toward implementing the combinations of capabilities necessary to perform essential mission tasks.

6. Apparatus

6.1 The equipment required to perform this test method includes a timer and the apparatus. The apparatus consists of linear inspection rails (used in all test configurations), walls, and optional terrain elements.

6.2 For the rectangular labyrinth and freeform maze test configurations, the main dimension to consider is the apparatus clearance width (W) for the robot and its ratio to minimum wall height (H). For this test method, W can be set to 120 cm [48 in.] with ±2.5 cm [1 in.] tolerance, 60 cm [24 in.] with ±1.3 cm [0.5 in.] tolerance, or 30 cm [12 in.] with ±1.3 cm [0.5 in.] tolerance; note that 240 cm [96 in.] is not an applicable value of W in this test method, but may be for other standards specified under Subcommittee E54.09. The applicable ratios of W:H vary based on the value of W, which results in seven possible apparatus dimensional settings: when W = 120 cm [48 in.], 1:2 ratio is available; when W = 60 cm [24 in.], 1:2, 1:3, or 1:4 ratios are available; and when W = 30 cm [12 in.], 1:2, 1:3, or 1:4 ratios are available. See Fig. 8 for a comparison of W and H apparatus dimensions as applied to the rectangular labyrinth test configuration.

6.3 Dimensions W and H should be chosen to represent the intended deployment environment or be based on the size of the robot (that is, the robot shall be able to maneuver within the selected dimensions of the apparatus), or both. All apparatus dimensions scale proportionally with W and H; linear rail length (L) is 0.75W, the positions of the linear rails are based on H (ground level, 0.25H, 0.5H, 0.75H, H), and the dimensions of the buckets and pipes (T) and visual acuity targets (V) used are matched to each possible value of W (see Fig. 9 and Fig. 10). A comparison of all apparatus dimensions can be found in Table 3. Resulting data from a combination of apparatus dimensions (that is, values of W, H, L, T, and V) is not comparable to data collected using apparatuses with different dimensions. The available combinations of apparatus dimensions are shown in Table 2.

6.4 For the embedded scenario test configuration, dimensions W and H are not applicable. However, dimensions L, T, and V shall be selected from the three possible pairs of dimensions shown in Table 3. The values selected for L and T should match the intended deployment environment to ensure that the linear inspection rails can physically fit in the desired locations and such that corresponding acuity for the target size matches relevant operations (for example, inspection license plates, inspecting shipment labels, etc.). When positioning the linear inspection rails in the environment, the height of each is allowed up to ±0.125H variance for each prescribed height (ground level, 0.25H, 0.5H, 0.75H, H) in order to fit within what is available in the scenario. For example, a table in an embedded scenario may not be exactly 0.5H high, but linear inspection rails that are viewable from above or below may still be positioned on it so long as the height falls within ±0.125H of 0.5H.

6.5 The rectangular labyrinth consists of four hallways, three rooms, and four alcoves positioned in a fixed layout that has an area of $20W^2$, with an opening on one end of the apparatus to be used as the start point (see Fig. 11). Lighting in the rectangular labyrinth shall be classified as either lighted (100 lx or greater) or dark (less than 1 lx). The lighting shall be measured throughout the apparatus, taking measurements in the 1W by 1W area occupied by each linear inspection rail and averaging the lux values. If the average lux value is not 100 lx

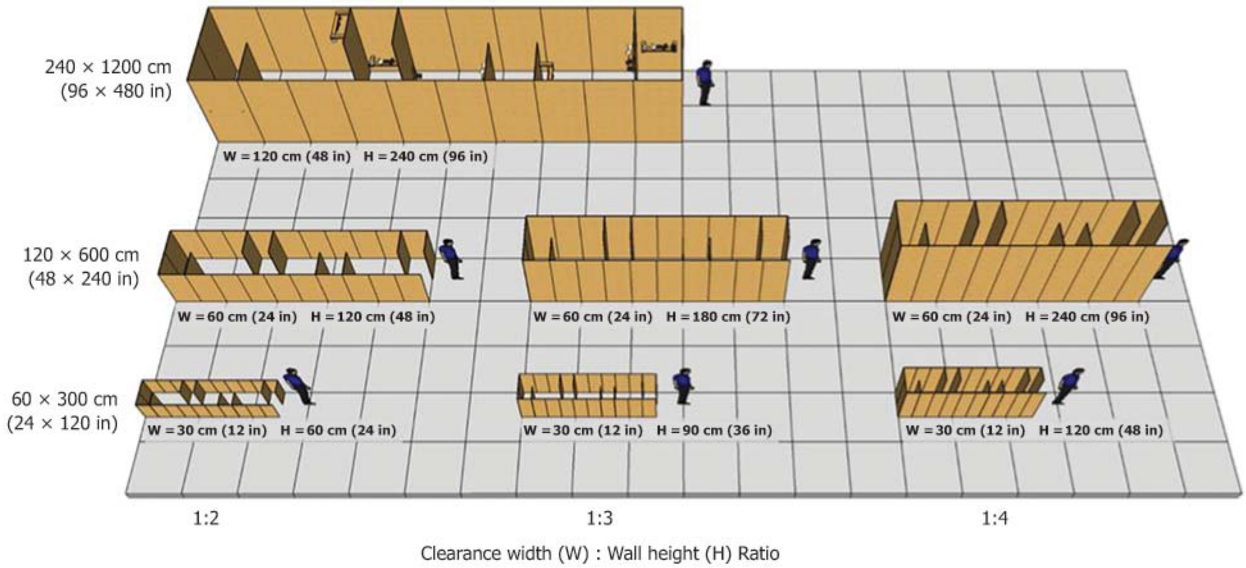

FIG. 8 The Rectangular Labyrinth Apparatus at Each Set of Apparatus Dimensions

or greater (that is, lighted) or less than 1 lx (that is, dark), the lighting should be adjusted in order to meet either condition. Resulting data from the rectangular labyrinth test configuration is comparable to data collected in other rectangular labyrinth tests using the same apparatus dimensions and lighting conditions.

6.6 The freeform maze consists of a minimum of four hallways, three rooms, and four alcoves, positioned in a variable layout that shall be determined by the test sponsor while maintaining the following characteristics:

6.6.1 An overall area that is between $40W^2$ and $80W^2$ (that is, two to four times the size of the rectangular labyrinth);

6.6.2 Each linear inspection rail must be positioned such that the robot must traverse at least 1W in length to reach the next linear inspection rail; and

6.6.3 A start point should be defined, which may be within the apparatus or as an opening on the outer border of the apparatus.

6.7 An example layout of the freeform maze is shown in Fig. 12. If the lighting in the freeform maze is consistent throughout, it shall be classified as either lighted (100 lx or greater) or dark (less than 1 lx). If the lighting is inconsistent throughout (for example, some areas are considered lighted and some are considered dark), the lux value of each 1W by 1W area occupied by each linear inspection rail will be noted on the report form. Resulting data from the freeform maze test configuration is only comparable to data collected in other freeform maze test configurations using the same layout of hallways, rooms, alcoves, walls, linear inspection rails, terrain, lighting conditions, and apparatus dimensions.

6.8 The walls of the rectangular labyrinth and freeform maze are made out of OSB panels or similar material measuring W wide by at least H tall (see Fig. 9 and Table 3 for dimensions). Wall panels are connected together using horizontal wooden posts on the outside of the apparatus and vertical wooden posts on the inside of the apparatus to form corners with other wall panels. Wooden posts measuring either W or 2W in length are used to connect wall panels on either side of the apparatus along the top for structural stability. See Fig. 13.

NOTE 1—If shipping containers are used as the apparatus, the metal walls of the containers are not required to be covered with OSB panels, unless so desired.

6.9 The embedded scenario test configuration is performed in a real-world environment with an overall area of at least $40W^2$ (that is, two times the size of the rectangular labyrinth). The environment can be expanded to include multiple floors of a building if desired. Fabricated walls, like those used in the rectangular labyrinth and freeform maze test configurations, can be added into an embedded scenario to increase complexity and serve as mounting points for linear inspection rails. It is recommended that the linear inspection rails be distributed throughout an environment rather than in close proximity to one another, in order to better encourage search operations from the robot and operator. An example layout of this test configuration is shown in Fig. 14. If the lighting in the embedded scenario is consistent throughout, it shall be classified as either lighted (100 lx or greater) or dark (less than 1 lx). If the lighting is inconsistent throughout (for example, some areas are considered lighted and some are considered dark), the lux value of each 1W by 1W area occupied by each linear inspection rail will be noted on the report form. Resulting data from the embedded scenario test configuration is only comparable to other embedded scenario tests using the same scenario/environment, layout of the environment and linear inspection rails, and lighting conditions.

6.10 The linear inspection rail is a length of wood, plastic, or metal measuring 0.75W length with two white visual acuity targets inside of black buckets or PVC pipes and two black visual acuity targets inside of white buckets or PVC pipes mounted to the post and a numeric label in the center; two of the buckets or PVC pipes are mounted normal to the rail (one

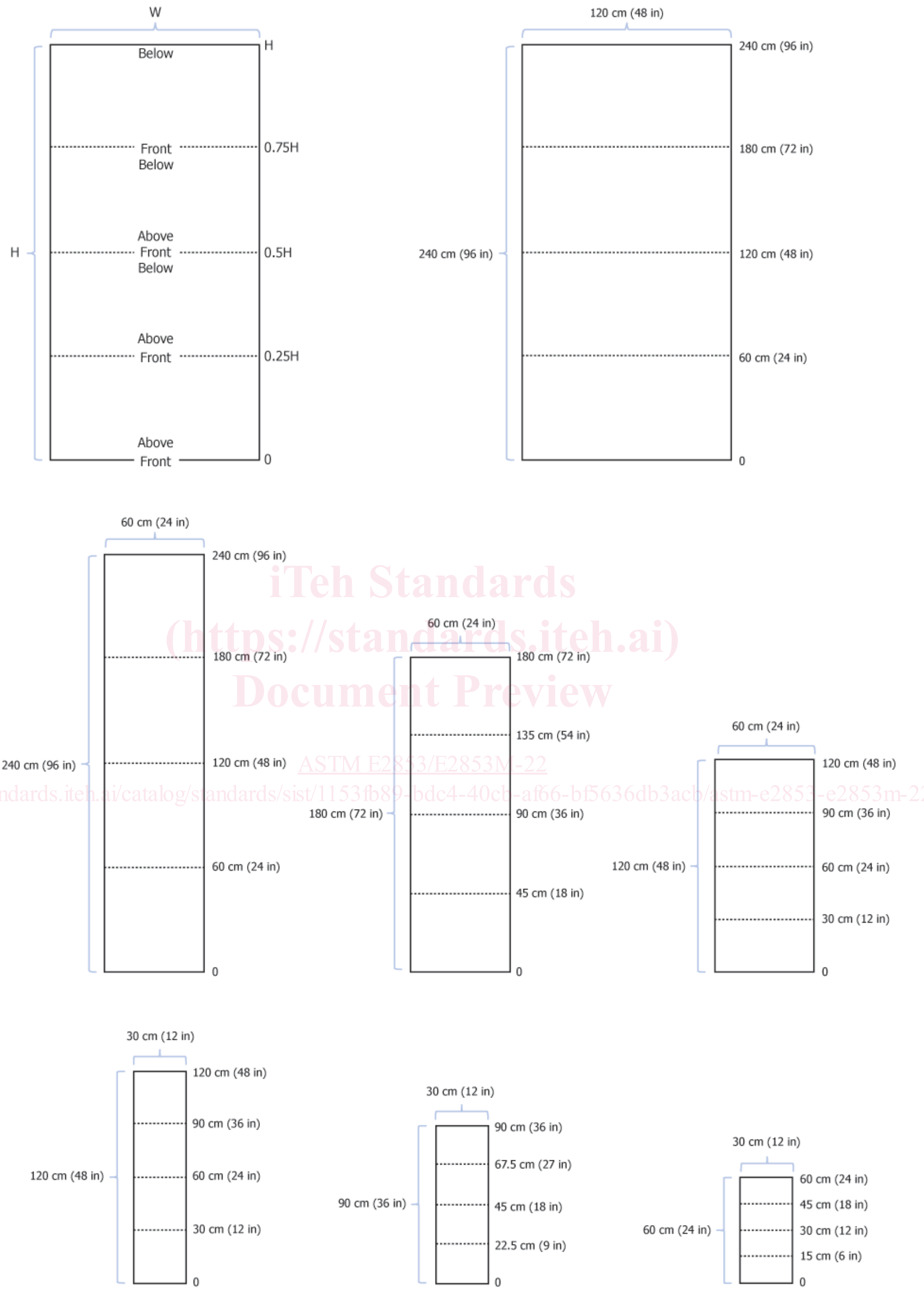

FIG. 9 Wall Panel Dimensions and Linear Rail Position Heights based on Apparatus Clearance Width (W) and Minimum Wall Height (H): Dimensional Layout (top left), W = 120 cm (top right), W = 60 cm (middle row), and W = 30 cm (bottom row)

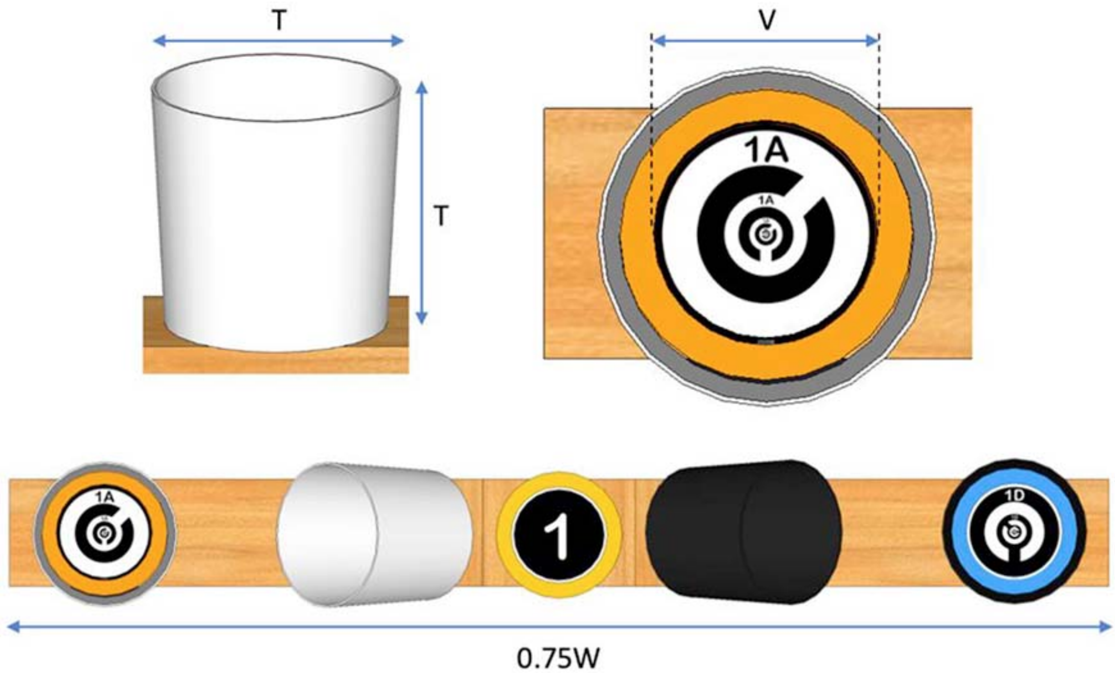

FIG. 10 Dimensional Layout of Buckets/pipes (top) and Linear Rails (bottom)

TABLE 3 Apparatus Dimensions Based on Intended Deployment Environments

Intended deployment environment	Apparatus clearance width (W)	Minimum wall height (H)	Ratio (W:H)	Linear rail length (L)	Target buckets/ pipes (T)	Visual acuity targets (V)	Linear rail height: 0.25H	Linear rail height: 0.5H	Linear rail height: 0.75H
Hallways and rooms	120 cm [48 in.]	240 cm [96 in.]	1:2	90 cm [36 in.]	10 cm [4 in.]	8.3 cm [3.25 in.]	60 cm [24 in.]	120 cm [48 in.]	180 cm [72 in.]
Bathrooms and closets	60 cm [24 in.]	240 cm [96 in.]	1:4	45 cm [18 in.]	5 cm [2 in.]	4 cm [1.5 in.]	60 cm [24 in.]	120 cm [48 in.]	180 cm [72 in.]
Public transportation	60 cm [24 in.]	180 cm [72 in.]	1:3	45 cm [18 in.]	5 cm [2 in.]	4 cm [1.5 in.]	45 cm [18 in.]	90 cm [36 in.]	135 cm [54 in.]
Cluttered interiors	60 cm [24 in.]	120 cm [48 in.]	1:2	45 cm [18 in.]	5 cm [2 in.]	4 cm [1.5 in.]	30 cm [12 in.]	60 cm [24 in.]	90 cm [36 in.]
Constrained spaces	30 cm [12 in.]	120 cm [48 in.]	1:4	22.5 cm [9 in.]	2.5 cm [1 in.]	2.1 cm [0.8 in.]	30 cm [12 in.]	60 cm [24 in.]	90 cm [36 in.]
Confined spaces	30 cm [12 in.]	90 cm [36 in.]	1:3	22.5 cm [9 in.]	2.5 cm [1 in.]	2.1 cm [0.8 in.]	22.5 cm [9 in.]	45 cm [18 in.]	67.5 cm [27 in.]
Voids in collapsed structures	30 cm [12 in.]	60 cm [24 in.]	1:2	22.5 cm [9 in.]	2.5 cm [1 in.]	2.1 cm [0.8 in.]	15 cm [6 in.]	30 cm [12 in.]	45 cm [18 in.]

white, one black) and two of the buckets or PVC pipes are mounted at a 45° angle (one white, one black), as shown in Fig. 2 and Fig. 10. The dimensions of the buckets or PVC pipes (T) and visual acuity targets (V) change based on the value of W (see Table 3).

6.11 The visual acuity targets consist of Landolt C symbols, which are used as described in Test Method E2566 (see Fig. 15). Each symbol consists of a ring with an outer diameter equal to five times the ring thickness displayed on a background of inverted color compared to the ring to maximize contrast. Visual acuity targets with black symbols on white backgrounds are used inside of white buckets/pipes and those with white symbols on black backgrounds are used inside of black buckets/pipes. The ring contains a gap with parallel edges equal to the ring thickness. The size of the gap represents the smallest discernible feature when measuring visual acuity and is reported as the metric. The gap appears in one of eight radial orientations around the ring at 45° intervals. Identifying gap orientations of Landolt C symbols with gaps of a particular size is related to the ability to resolve visual identification of objects of that size. Five Landolt C symbols are arranged in a concentric manner, with the largest 50 % of the diameter of the overall target and each successive symbol 40 % of the diameter of the previous. The smallest optotype that can be resolved