



Designation: E 1038 – 98

## Standard Test Method for Determining Resistance of Photovoltaic Modules to Hail by Impact with Propelled Ice Balls<sup>1</sup>

This standard is issued under the fixed designation E 1038; 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 ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

### 1. Scope

1.1 This test method provides a procedure for determining the ability of photovoltaic modules to withstand impact forces of falling hail. Propelled ice balls are used to simulate falling hailstones.

1.2 This test method defines test specimens and methods for mounting specimens, specifies impact locations on each test specimen, provides an equation for determining the velocity of any size ice ball, provides a method for impacting the test specimens with ice balls, provides a method for determining changes in electrical performance, and specifies parameters that must be recorded and reported.

1.3 This test method does not establish pass or fail levels. The determination of acceptable or unacceptable levels of ice ball impact resistance is beyond the scope of this test method.

1.4 The size of the ice ball to be used in conducting this test is not specified. This test method can be used with various sizes of ice balls.

1.5 This test method may be applied to concentrator and nonconcentrator modules.

1.6 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.7 *This standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* For specific precautionary statements, refer to 5.1, Section 6, Note 8, and Note 9.

### 2. Referenced Documents

#### 2.1 ASTM Standards:

E 772 Terminology Relating to Solar Energy Conversion<sup>2</sup>

<sup>1</sup> This test method is under the jurisdiction of ASTM Committee E-44 on Solar, Geothermal, and Other Alternative Energy Sources and is the direct responsibility of Subcommittee E44.09 on Photovoltaic Electric Power Systems.

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<sup>2</sup> *Annual Book of ASTM Standards*, Vol 12.02.

E 822 Practice for Determining Resistance of Solar Collector Covers to Hail by Impact with Propelled Ice Balls<sup>2</sup>

E 1036 Test Methods for Electrical Performance of Non-concentrator Terrestrial Photovoltaic Modules and Arrays Using Reference Cells<sup>2</sup>

E 1328 Terminology Relating to Photovoltaic Solar Energy Conversion<sup>2</sup>

E 1462 Test Methods for Insulation Integrity and Ground Path Continuity of Photovoltaic Modules<sup>2</sup>

### 3. Terminology

3.1 *Definitions*—For definitions of terms used in this test method, see Terminology E 772 and Terminology E 1328.

3.2 *Symbols*—The following symbols are used in this test method.

$m$  = ice ball mass, g,

$d$  = ice ball diameter, mm, and

$r$  = ice ball radius, mm.

#### 3.2.1 Velocity:

$V_t$  = ice ball terminal,  $m\ s^{-1}$ ,

$V_w$  = wind,  $m\ s^{-1}$ , and

$V_r$  = ice ball resultant,  $m\ s^{-1}$ .

### 4. Significance and Use

4.1 In many geographic areas, there is concern about the effect of falling hail upon photovoltaic modules. This test method may be used to determine the ability of photovoltaic modules to withstand the impact forces of hailstones. In this test method, the ability of a photovoltaic module to withstand hail impact is related to its tested ability to withstand impact from ice balls. The effects of impact may be either physical or electrical degradation of the module.

4.2 This test method describes a standard procedure for mounting the test specimen, conducting the impact test, and reporting the effects.

4.2.1 The procedures for mounting the test specimen are provided to assure that modules are tested in a configuration that relates to their use in a photovoltaic array.

4.2.2 Six or more impact locations are chosen to represent vulnerable sites on modules and general locations are listed in Table 1. Only a single impact is specified at each of the impact locations.

4.2.3 Resultant velocity is used to simulate the velocity that may be reached by hail accompanied by wind. The resultant velocity used in this test method is determined by vector addition of horizontal velocity to the vertical terminal velocity.

4.2.4 Ice balls are used in this test method to simulate hailstones. Hailstones are variable in properties such as shape, density, and frangibility (for fracture characteristics, see Ref (10) in Practice E 822). These properties affect factors such as the duration and magnitude of the impulsive force acting on the module and the area over which the impulse is distributed. Ice balls (with a density, frangibility, and terminal velocity near the range of hailstones) are the nearest hailstone approximation known at this time. Ice balls generally are harder and denser than hailstones; therefore, an ice ball simulates the worst case hailstone. Perhaps the major difference between ice balls and hailstones is that hailstones are more variable than ice balls. Ice balls can be uniformly and repeatedly manufactured to assure a projectile with known properties.

4.3 Data generated using this test method may be used for the following: (1) to evaluate impact resistance of a module, (2) to compare the impact resistance of several modules, (3) to provide a common basis for selection of modules for use in various geographic areas, or (4) to evaluate changes in impact resistance of modules due to other environmental factors, such as weathering.

4.3.1 This test method requires analysis of visual effects, as well as electrical measurements. Visual effects are generally more sensitive than the electrical measurements; therefore, the absolute values for voltage and current are not critical, but repeatable conditions for before and after tests are required for determining electrical changes.

4.3.2 A range of observable effects may be produced by impacting various types of photovoltaic modules. Physical effects on modules may vary from no effect to penetration by the ice ball. Some physical changes in the module may be visible when there is no apparent electrical degradation of the module.

**TABLE 1 Candidate Locations and Suggested Order for Impact Points**

Location number	Description
1	Centers of cells
2	Edges of cells, especially near electrical contacts
3	Points of minimum spacing between cells
4	Points of maximum distance from points of support in 6
	Corners and edges of the module
5	Points of support for any superstrate material
6	Back of module, if exposed in stowed orientation
7	Electrical terminals and leads
8	Centers of lenses approximately 50 mm from lens support points
9	

4.3.3 Electrical changes may vary from no effect to no output. All effects of the impacts must be described in the report so that an estimate of their significance can be made.

4.4 This test method does not specify the size or velocity of ice balls or maximum number of impacts to be used in making the test. These determinations will be based on frequency and severity of expected hail occurrences and the intent of the testing.

4.4.1 If the testing is being performed to evaluate impact resistance of a single module, or several modules, it may be desirable to repeat the test using several sizes and velocities of ice balls. In this manner, the different effects of various sizes and velocities of ice balls may be determined. However, no point shall be impacted more than once (see 7.10).

4.4.2 The size and frequency of hail varies significantly among various geographic areas. If testing is being performed to evaluate modules intended for use in a specific geographic area, the ice ball size should correspond to the level of hail impact resistance required for that area. Information on hail size and frequency can be found in Appendix X1 of Practice E 822 and footnotes 3 and 4 of this test method, or may be available from local historical weather records.

4.4.3 When testing modules that are designed to be in a stowed position during hail storms, additional impact locations should be chosen accordingly.

4.5 The hail impact resistance of modules may change as the materials are exposed to various environmental factors. This test method may be used to evaluate degradation by comparison of hail impact resistance data measured before and after exposure to other such environmental factors.

## 5. Apparatus

5.1 *Launcher*, capable of propelling a selected ice ball at the specified velocity within  $\pm 5\%$ . The aiming accuracy of the launcher must be sufficient for the ice ball to strike the specified impact area, or the surrounding area must be masked for protection from inadvertent impacts.

NOTE 1—Launchers that have proven suitable utilize a compressed air supply, an accumulator tank, a large diameter quick-opening valve, and interchangeable barrels to accommodate different sizes of ice balls<sup>3,4</sup> (see Ref (14) of Practice E 822). Another launcher that has been used is a table-mounted slingshot with an adjustable hand rest.

5.2 *Velocity Meter*, for measuring ice ball velocity to within  $\pm 2\%$ .

5.3 *Test Base*—A rigid mount for supporting the test module in a fashion that simulates actual mounting applications.

5.4 *Molds*, for casting spherical ice balls of appropriate diameter.

NOTE 2—Molds made from silicone rubber or expanded polystyrene have been found suitable.

<sup>3</sup> Moore, D., and Wilson, A., "Photovoltaic Solar Panel Resistance to Simulated Hail," *Low-Cost Solar Array Project Report 5101-62*, Jet Propulsion Laboratory, Pasadena, CA, 1978. Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161-0001.

<sup>4</sup> Jenkins, D. R., and Mathey, R. G., "Hail Impact Testing Procedure for Solar Covers," NBSIR 82-2487, National Bureau of Standards, April 1982. Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161-0001.