

PACT Stress Testing Protocol

Version 0.4.0

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Contents

1. Introduction.....	3
2. Definitions and References.....	3
3. Required equipment.....	3
4. Protocol Details	3
5. Protocol Validation	5
6. Version History	5

1. Introduction

The purpose of this protocol is to use accelerated stress testing to assess the durability of metal halide perovskite (MHP) photovoltaic (PV) modules. In its current form, the protocol provides a minimum sequence of stress tests that will provide some confidence that MHP modules can retain more than 80 % of initial efficiency after 10 weeks of field operation. This protocol is intended to be used to determine whether modules should be field deployed, or if they could be expected to fail within 10 weeks.

The current protocol has three test legs. The first is a control sample leg where a sample is exposed to no stress. The second leg is designed to examine the robustness of the package. A suggested package design is provided on the PACT website; <https://pvfact.sandia.gov/publications-and-protocols/>. The packaging leg only needs to be used on a new package design, or if changes are made to a previously tested package design or process. The third leg is the light and elevated temperature stress leg.

2. Definitions and References

- MHP: Metal Halide Perovskite
- PV: Photovoltaic
- LT: Light and elevated temperature
- IEC 61215:2021: defines requirements for the design qualification and type approval of terrestrial photovoltaic (PV) modules suitable for long-term operation in general open-air climates
- MHP ISOS protocols: “Consensus statement for stability assessment and reporting for perovskite photovoltaics based on ISOS procedures” <https://doi.org/10.1038/s41560-019-0529-5>

3. Required equipment

- AM1.5 light soaking chamber with UV (400 nm) filters and sample temperature control of 50 to 90 ± 5 °C. CCC class simulation is sufficient.
- Damp heat testing chamber capable of operating IEC 61215:2021 MQT 13 profile
- Thermal cycling chamber capable of operating IEC 61215:2021 MQT 11 profile
- Humidity Freeze chamber capable of operating IEC 61215:2021 MQT 12 profile

4. Protocol Details

Figure 1 outlines version 0.4.0 of the accelerated stress testing protocol. Prior to any stress testing it is recommended the modules be characterized by visual inspection and performance characterization.

The protocol is then divided into three testing legs: Control, package-focused and LT-focused testing sequences. The package-focused test is a modified test sequence from IEC 63209-1 sequence 3. This test

leg is designed to identify package failures such as delamination and moisture ingress. A pass/fail criteria is applicable as defined by IEC 61215-1:2021 clause 8, where no major visual defects are observed. An optional inclusion of calcium evaporated on polyethylene terephthalate substrate inside the package can be used for increased confidence in the moisture impermeability, but it is not a requirement.

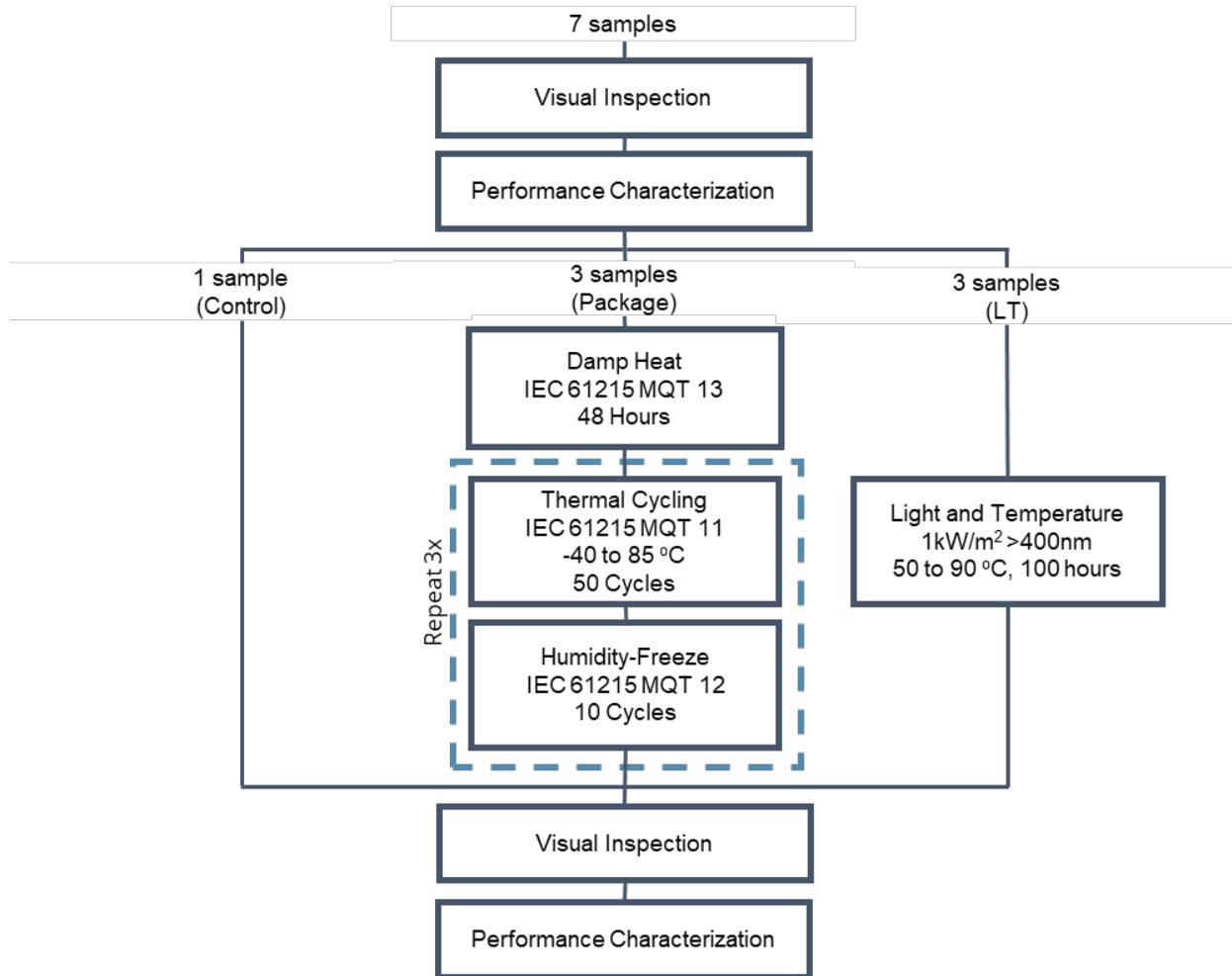


Figure 4. Test flow for examination of the package impermeability.

The MHP-focused test is a supplement to IEC 61215:2021 which is expected to be used in addition to the module qualification tests outlined in the standard. The supplement focuses on light and elevated temperature stress which is demonstrated to affect the performance of some metal halide perovskites and is not covered by IEC 61215:2021.

Light and elevated temperature: A minimum sample temperature of 50 °C is required at 1000 kW/m² for 100 hours. PV module temperatures can reach 90 °C under certain mounting configurations during outdoor deployment, so a maximum temperature of 90 °C is recommended. Sample temperature should be measured from the rear (non-illuminated) surface of the module. Samples are recommended to be maximum power point tracked during exposure. UV exposure has not been validated for this test. Light

sources that replicate AM1.5 spectrum (with a cut at 400 nm) such as Xenon-arc, Metal-halide or LED are recommended.

5. Protocol Validation

Significant validation efforts have been conducted for LT testing at 50 °C. Validation includes subjecting samples from the same batch to field testing. A manuscript for this validation is currently in preparation. This document will be updated when the validation study is published.

6. Version History

- Version 0.1 – 3/14/2022 – Initial release.
- Version 0.2 – 8/1/2022 – Changed UV testing requirements to specify dose in kWh/m² and adjusted module temperature from 60 to 75° C to be in line with Light and Elevated Temperature test.
- Version 0.2.1 – 10/18/2022 – Further adjustments to UV testing requirements to specify dose in the UV range 280 to 400 nm. Additional clarification on the UV spectrum requirements which align with UV preconditioning specifications outlined by IEC 61215:2021 MQT 10.
- Version 0.3 – 4/31/2024 – Leg 2 is now referred to as a supplement to IEC 61215:2021. It is recommended that modules are also tested according to the MQTs outlined in IEC 61215:2021. Updated the light and temperature conditions recommendation to configure modules in MPPT. The light and elevated temperature conditions were updated such that a minimum sample temperature of 75 °C was recommended with an ultimate recommendation for 90 °C.
- Version 0.4.0 – 3/05/2025 – Cleaned up the protocol boxes: Removed reference to a precondition (this can be returned when a precondition protocol is developed and validated). Removed reference to an Asymptotic method for performance characterization. Module characterization box removed, it folds into Performance Characterization. Light and elevated temperature test changed to 100 hours and reduced to 50C to align with current recommendations. Test Legs have been combined to a single figure to demonstrate that they are done in parallel and intended to be on a single module batch. Added a control leg to the test flow. Also removed the disclaimer that says the test has not been validated and expanded on the Protocol Validation section to include progress made on validation and the preparation of a publication. Updated equipment requirements.

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