Accelerated Weathering Testing Principles to estimate the Service Life of OPV Modules

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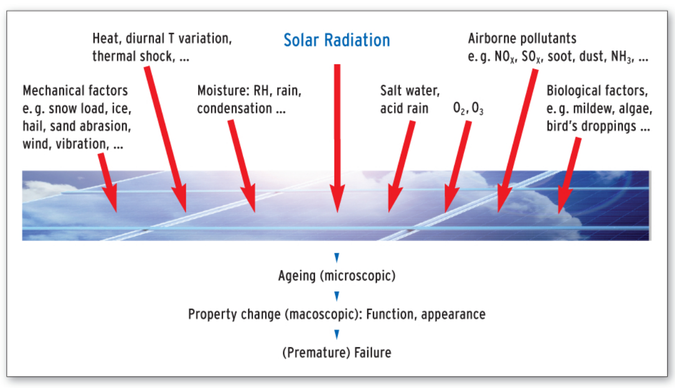
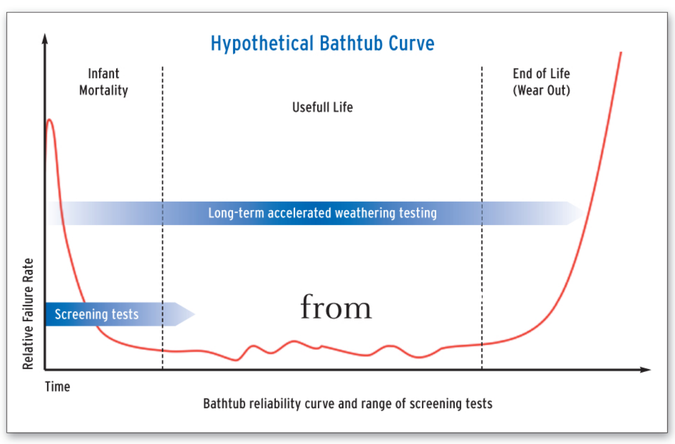
Reliability Testing of PV Modules ... vs. Long-term Durability Testing

- Outdoor testing necessary to understand failure modes of PV systems, but unacceptably long for decision making.
- Faster ways to predict the reliability of crystalline PV systems rely extensively on Highly Accelerated Life Testing (HALT).
- However HALT are screening tests meant to detect early life failures resulting from materials, design and processing issues that might happen after few years in the field.
- **Design qualification standards** for PV modules (using HALT) screen for "**infant mortality**" on bathtub reliability curve.
- In contrast to crystalline and thin-film PV technologies, OPV technologies do not benefit from standardized design qualification and safety protocols.
- While philosophy of IEC standards may be applicable to OPV, relevance of HALT protocols for polymer-made products needs to be investigated.





- By contrast to reliability testing, durability testing focuses on longer term in-service period where **repeated application of combined environmental stresses accumulates damage** which cause wear-out and eventual failure → Durability is a component of reliability.
- **Environmental durability** of materials impacted by combined effects of **solar radiation, heat, moisture, oxygen,** temperature and moisture cycles + secondary stressors.
- Accelerated weathering testing used for decades by established industries (automotive, plastics & coatings, building materials, etc. ...) to predict durability of polymer-based products.
- Typically addresses **useful life** and **end of life** on bathtub reliability curve.
- May prove highly beneficial for OPV testing and material qualification.

Procedure for Estimating Service Life of OPV Systems

Step 1 – Problem definition

- In-service performance requirements and criteria
- Characterize product, materials and end-use environments
- Run modified FMEA to identify failure modes, root causes and degradation mechanisms
- Understand type and range of degradation factors of importance
- Determine worst-case conditions in end-use environment

Step 2 – Pre-testing

To demonstrate that rapid changes in material properties can be induced by exposure to extreme levels of individual or combined degradation factors. Relies on HALT and HASS

- Supports (or rules out) assumptions/findings made during FMEA
- Determines order of importance for degradation factors
- Provides guidance on applicable levels of degradation factors

Step 3 – Design Test Program

- Test Program: set of test methods (existing or newly designed) intended to test response of product to specific or combination of environmental stresses. Include natural and accelerated laboratory weathering + other ALT
- Determine test specimen types, number and sizes
- Specify evaluation intervals and techniques

Step 4 – Validation of Test Program

- Initiate long-term outdoor exposure(s) at benchmark climates (e. g. hot humid, hot dry, coastal, cold temperate)
- Implement Test Program. May take several months
- Measure and compare property change rates and other criteria of laboratory and (when available) outdoor tests
- Determine correlation and acceleration factor

What makes an Accelerated Weathering Test Method predictive?

REALISTIC

Same stress factors, failure modes and degradation mechanisms as in real life

Correlation of change in properties between laboratory and real life / field results with statistical tools, analytical techniques to determine degradation mechanisms

ACCELERATED

To get answers as quickly as possible

Primarily obtained via controlled increase of stress factors levels. For composite products, cycling of test parameters recommended (temperature, and humidity mainly)

PRECISE

Acceptable repeatability and reproducibility

Precision affected by repeatability of the testing devices, operators skills, variations in test specimens production process. Monitored through using controls of known performance

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