Enhanced Stress Tests for the Reliability of Integrated and Floating Photovoltaics

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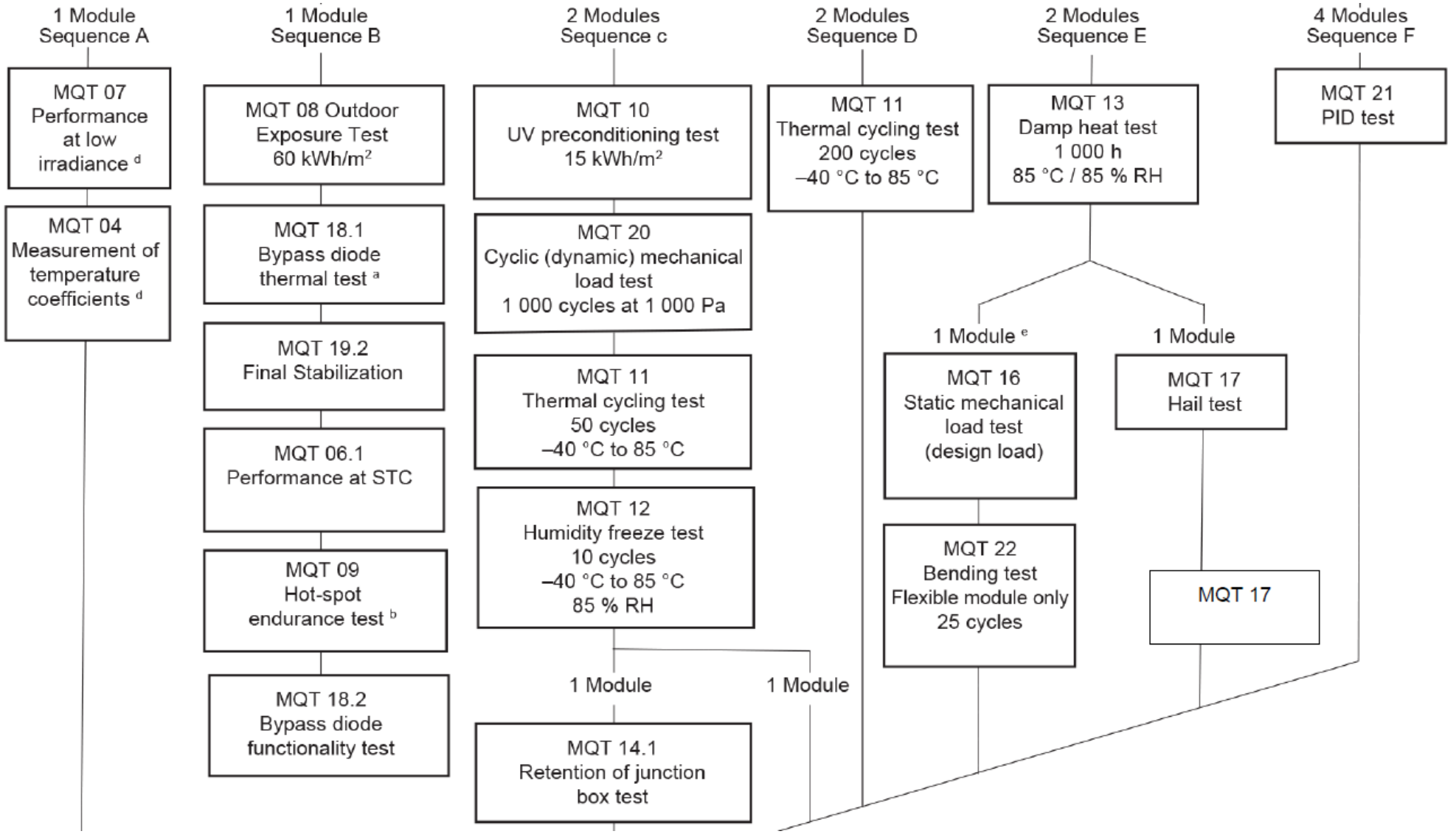
Integrated PV

Need to rethinking the qualification standards?

IEC 61215:2021

What are the most common tests that PV module suppliers carry out?



Other non- (or quasi-) standard challenges:

- Extended UV, Temp., RH, etc.
- LETID?
- IAM?

IEC 61215:2021

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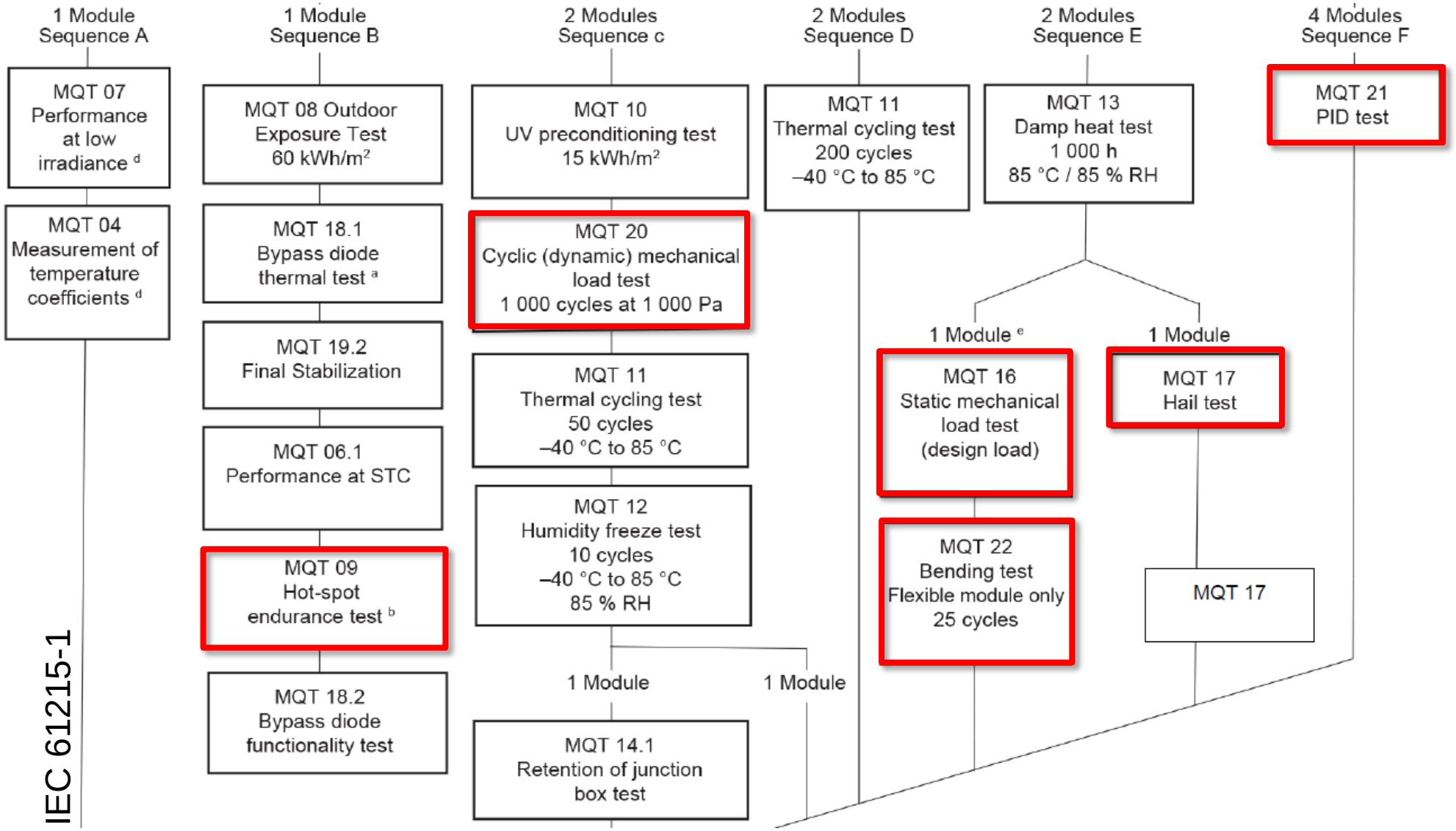

New stresses for IPV

	Mechanical tests	Thermal tests	Irradiance tests	Chemical tests
BIPV	• Structural performance	• Heat transmittance	• IAM • UV discoloration • Hot spot (multi-colour) • Reflectance/glare	
VIPV	• Vibration test • Stone impact • Sand abrasion • Noise reduction • Aerodynamic test	• Heat transmittance	• IAM (curvature) • Hot spot (curvature)	• Salt spray corrosion
Agro-PV	• Vibration test • Stone impact • Sand abrasion • Sand fall	• Heat transmittance • PID + salt mist / sand fall	• IAM (for vertical installations)	• Salt spray corrosion • Ammonia corrosion
Floating-PV	• Dynamic torsion • Shock/drop	• PID + salt mist		• Salt mist corrosion • Ammonia corrosion
Urban-PV	• Vibration test • Stone impact • Shock/drop • Noise reduction		• IAM (vertical PV) • UV discoloration • Hot spot (multi-colour) • Reflectance/glare	• Soiling cementation?

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FPV: What can be taken from experience

"Where Sun Meets Water – Floating Solar Handbook for Practitioners", World Bank Group, ESMAP and SERIS (2019)

TABLE 4.4 Potentially accelerated FPV module failure modes and mitigation strategies

Environmental stresses	Failure mode	Mitigation strategies
Moisture	• Corrosion • Hydrolysis • PID	• Moisture hardened materials • Encapsulants: TPO, POE, ionomer • Backsheets: glass, aluminized PID resistant cells • System level PID compensation
Mechanical stresses	• Interconnect fatigue • Cell cracking	• Increase module stiffness • Cells and string on neutral axis • Cut cells (for fatigue) • Lower modulus encapsulants • Multi-busbar/wire interconnects
Hot-spot/shading	• Arcing • Melting/cracking • Diode failure	• Less cells per bypass diode • Higher RTI materials • Anti-soiling coatings

Source: Adapted from Harwood 2018.

Note: PID = potential induced degradation; TPO = thermoplastic polyolefin; POE = polyolefin; RTI = relative temperature index.

FPV: What can be taken from experience

"Where Sun Meets Water – Floating Solar Handbook for Practitioners", World Bank Group, ESMAP and SERIS (2019)

Source: © SERIS.

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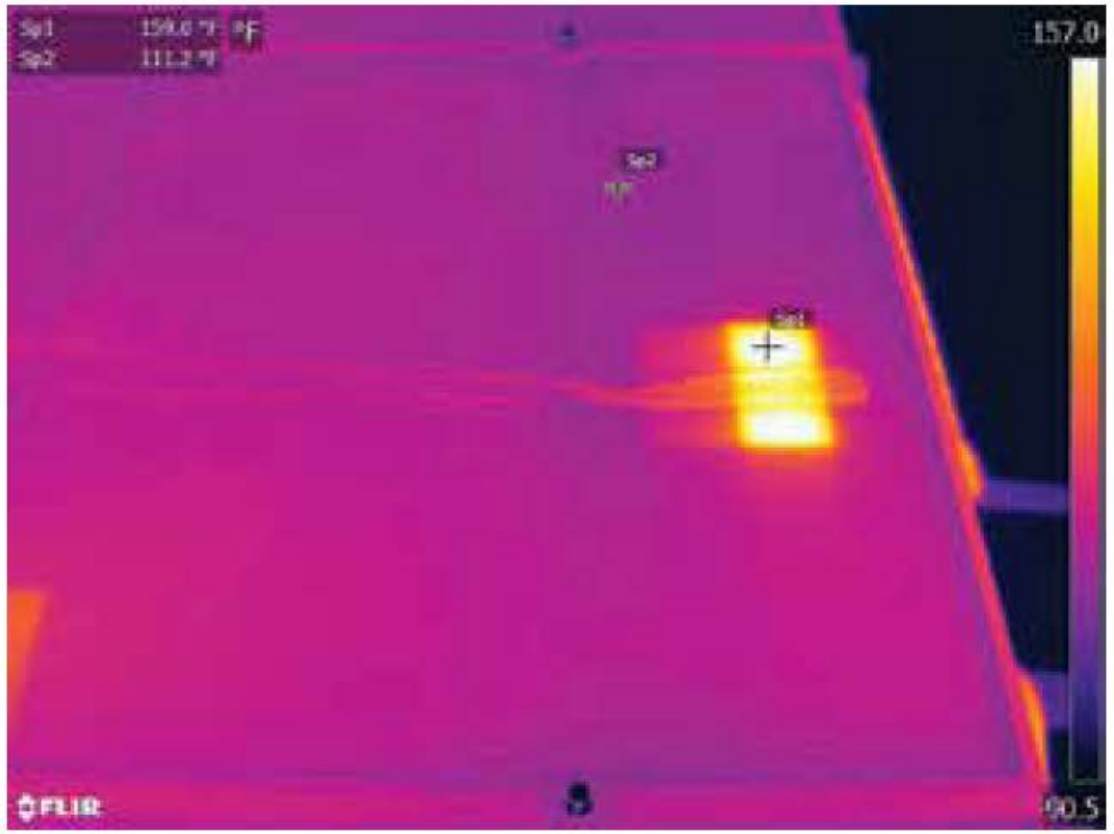

Source: © SERIS.

FPV: What can be taken from experience

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FIGURE 9.15 Connectors and cables submerged in water

Source: © SERIS.

FPV: What can be taken from experience

"Where Sun Meets Water – Floating Solar Handbook for Practitioners", World Bank Group, ESMAP and SERIS (2019)

FIGURE 9.22 Animal visits

Source: © SERIS.

FPV: What can be taken from experience

"Where Sun Meets Water – Floating Solar Handbook for Practitioners", World Bank Group, ESMAP and SERIS (2019)

TABLE A.1 Accelerated testing for floating solar module failure modes in various operating environments

Environmental stresses	Failure mode	Moderate stress	Higher stress	Highest stress
Moisture	• Corrosion • Hydrolysis • PID	Test at 85C/85% RH, 1,000hrs, Salt mist	Test at 85C/85% RH, 2,000hrs	Test at 85C/85% RH, 3,000hrs+ 120C/100%RH
		●	▼	
Mechanical stresses	• Interconnect fatigue • Cell cracking	Static mechanical load test 5,400Pa	Dynamic mechanical load test, 1000Pa/1000cyc	Shock/Vibration/HALT test
		●	▼	
Hot-spot/shading	• Arcing • Melting/cracking • Diode failure	Temperature test Diode test	Extended shading tests	High temperature operating life test
		●	▼	◆

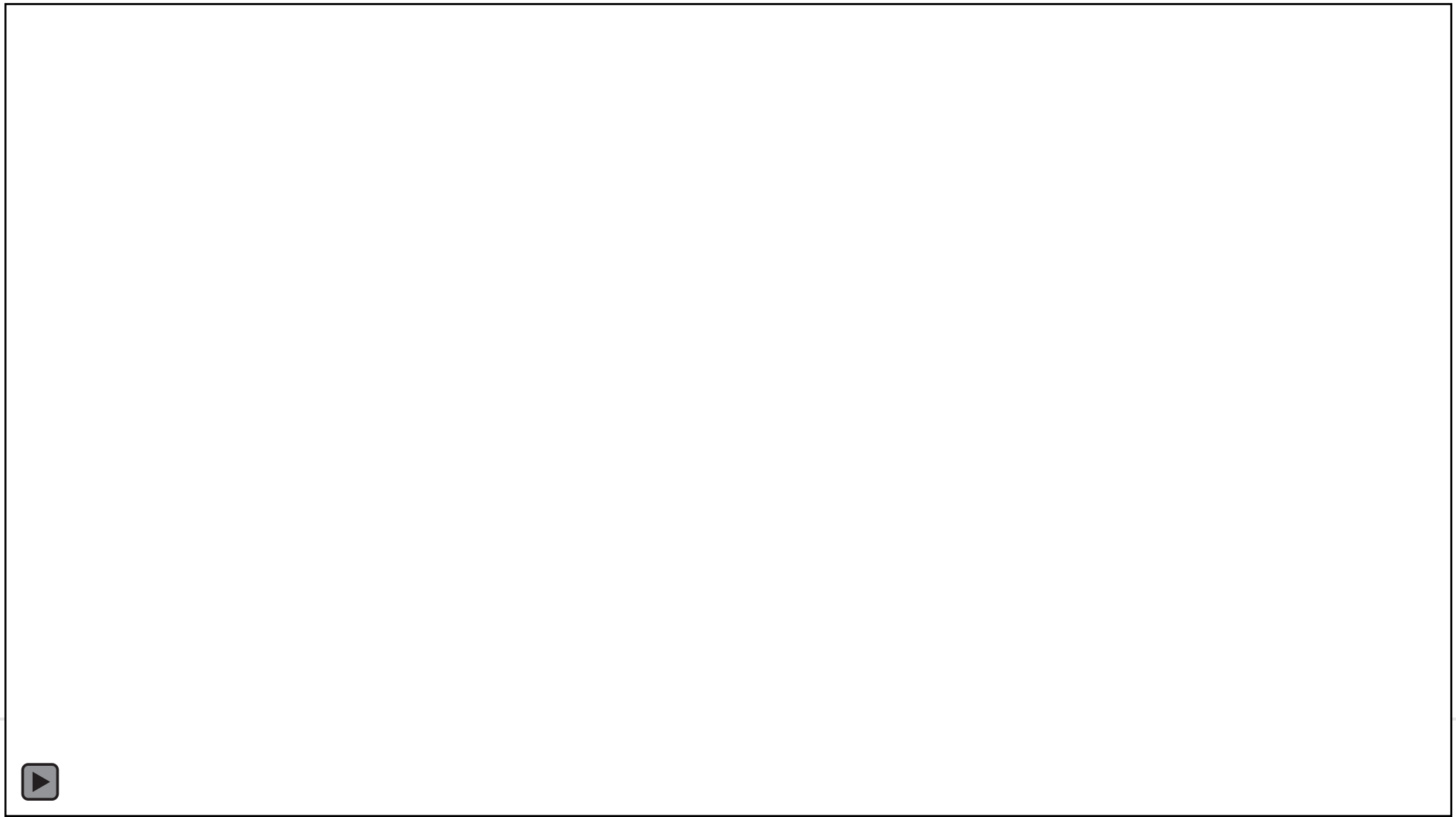
● Temperate environment ◆ Desert environment ▼ Tropical environment Floating environment

Source: Harwood 2018.

Notes: PID = potential induced degradation; C = degree Celsius; RH = relative humidity; hrs = hours; Pa = Pascal; HALT = Highly Accelerated Life Test; HTOL = high temperature operating life.

New mechanical stresses for FPV

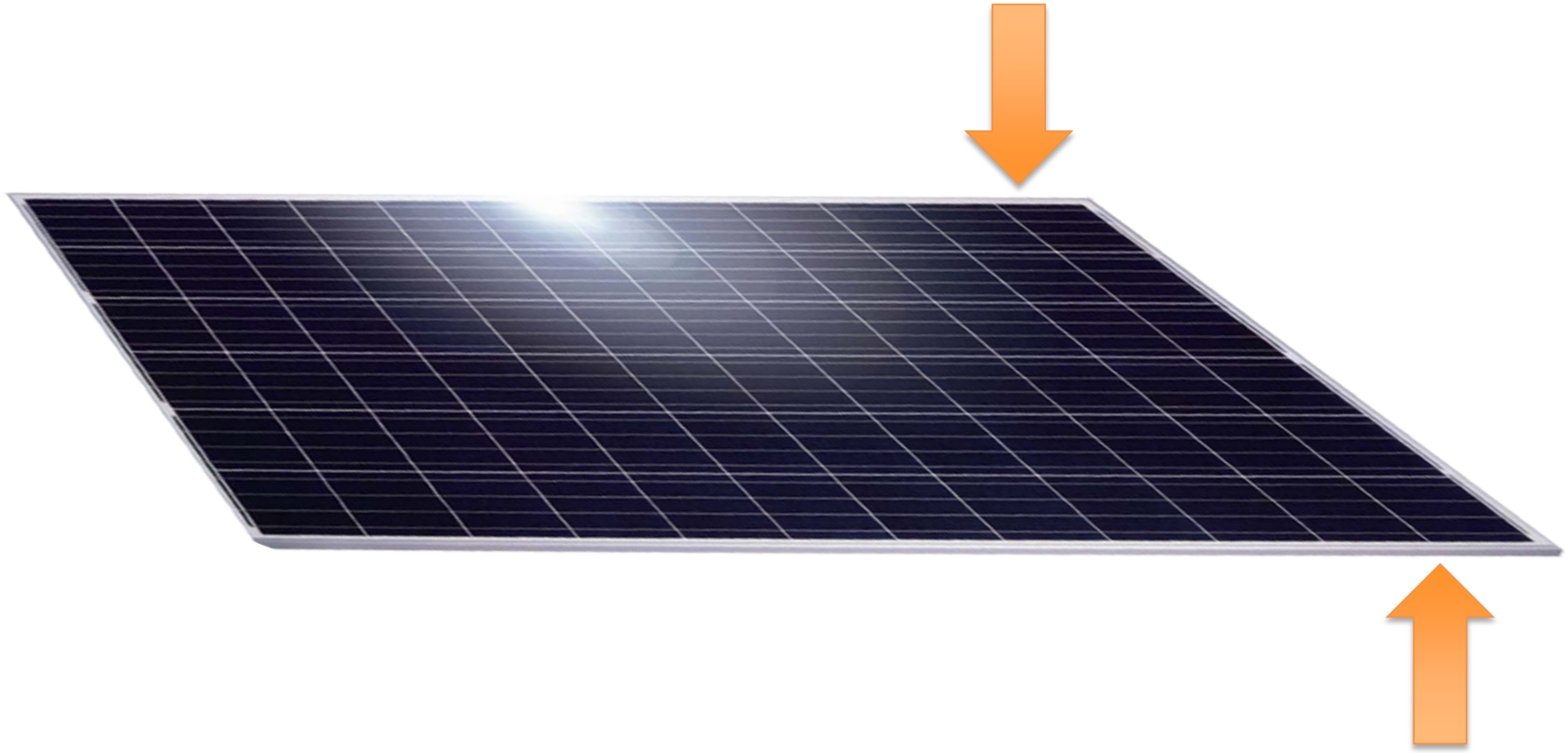
What failure modes should be tested for in addition when deploying PV modules offshore?



https://www.pv-magazine.com/2020/11/06/floating-pv-systems-are-storm-resistant/

New mechanical stresses for FPV

What tests would SERIS propose, to address these failure modes?



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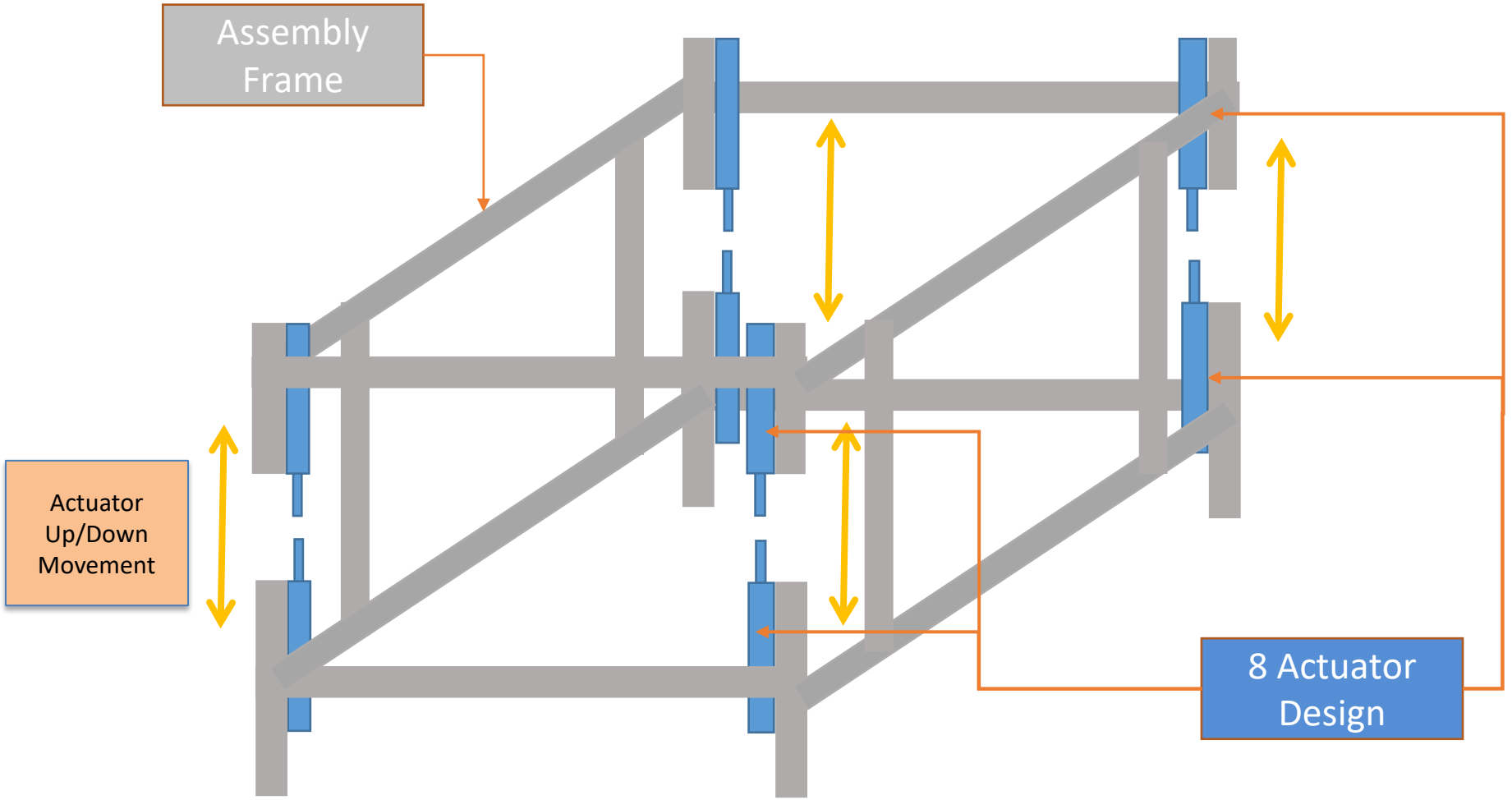


What can be taken from ISO standards

ISO 19904-1:2019: Petroleum and natural gas industries - Floating offshore structures, Part 1

Part 1

- Ship-shaped, semi-submersible, spar and shallow-draught cylindrical structures

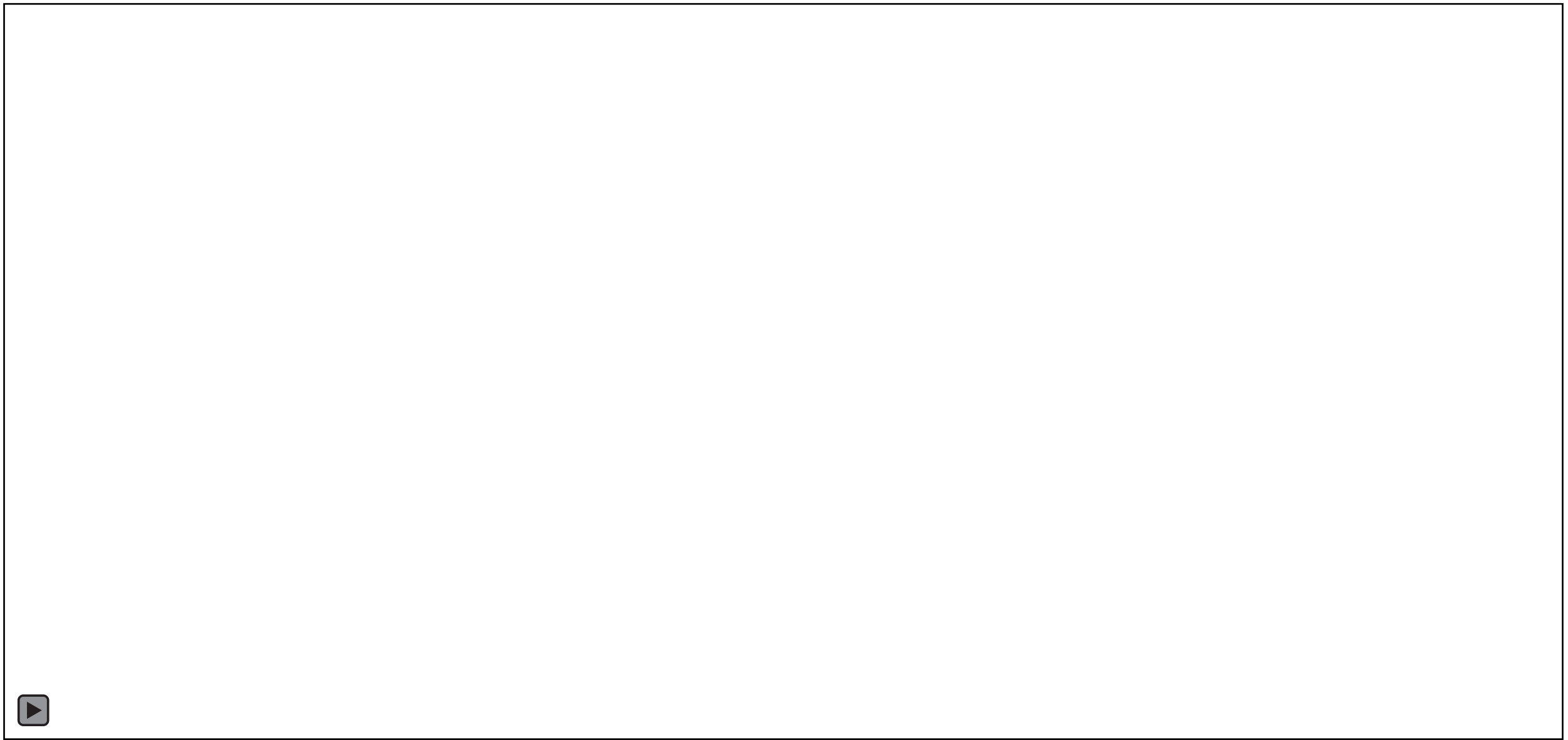
Definition of stresses:

- **Slamming:** impulsive action with high pressure peaks that occurs during impact between a portion of the structure and water
- **Splash zone:** part of a structure that is intermittently exposed to air and to sea water
- **Watertight:** capable of preventing the penetration of water into the structure during temporary exposure to water

- Proposed approach:
  - To define a slamming action Fs for the geometry of PV modules, depending on:
    - Water density, water particle velocity, module dimensions
    - Correlation to wet or dry test (drop test on water or on a selected surface)
    - Number of tests and linearity analysis

Wave shock

Simulated with drop test: **ongoing**



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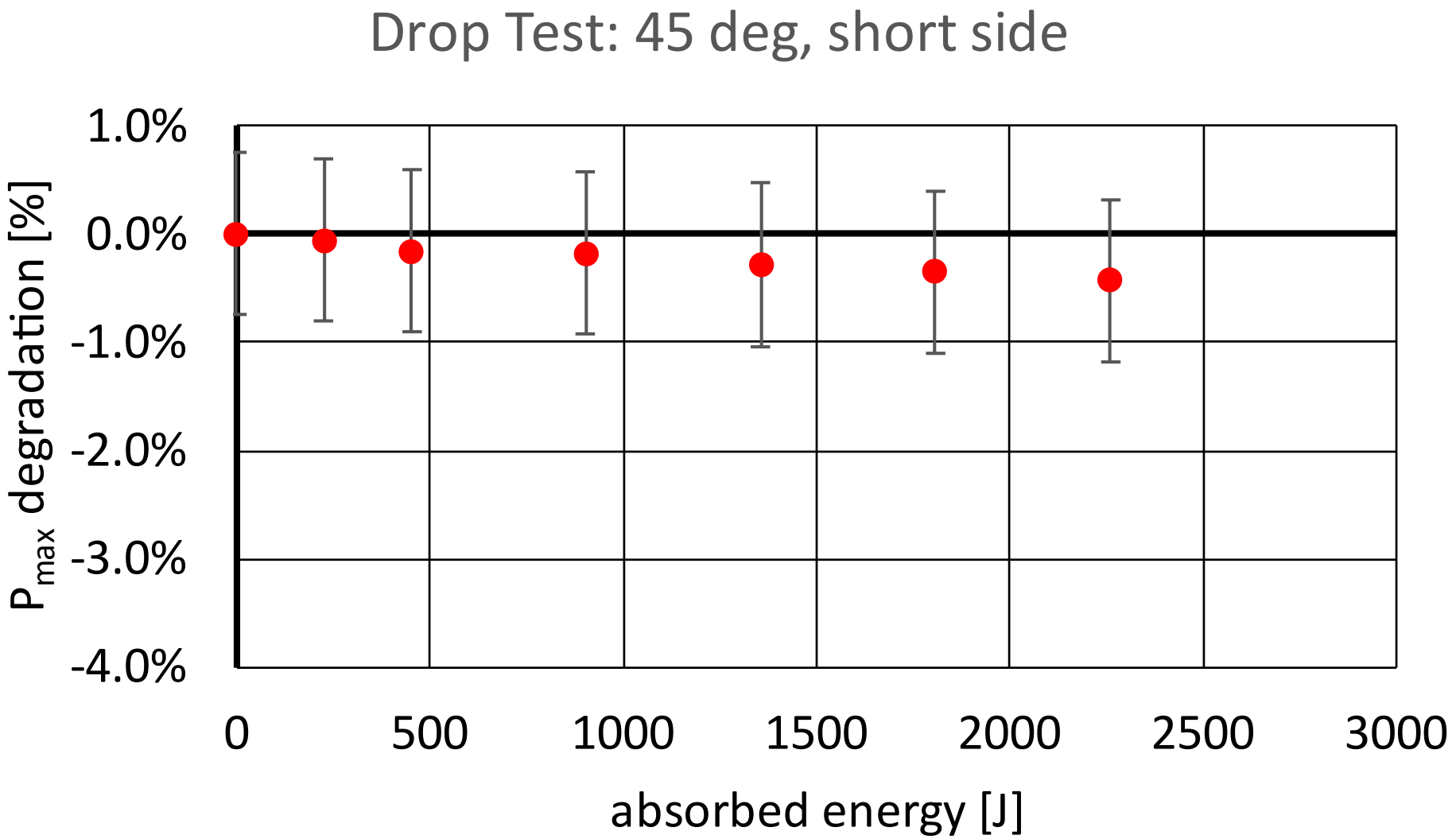

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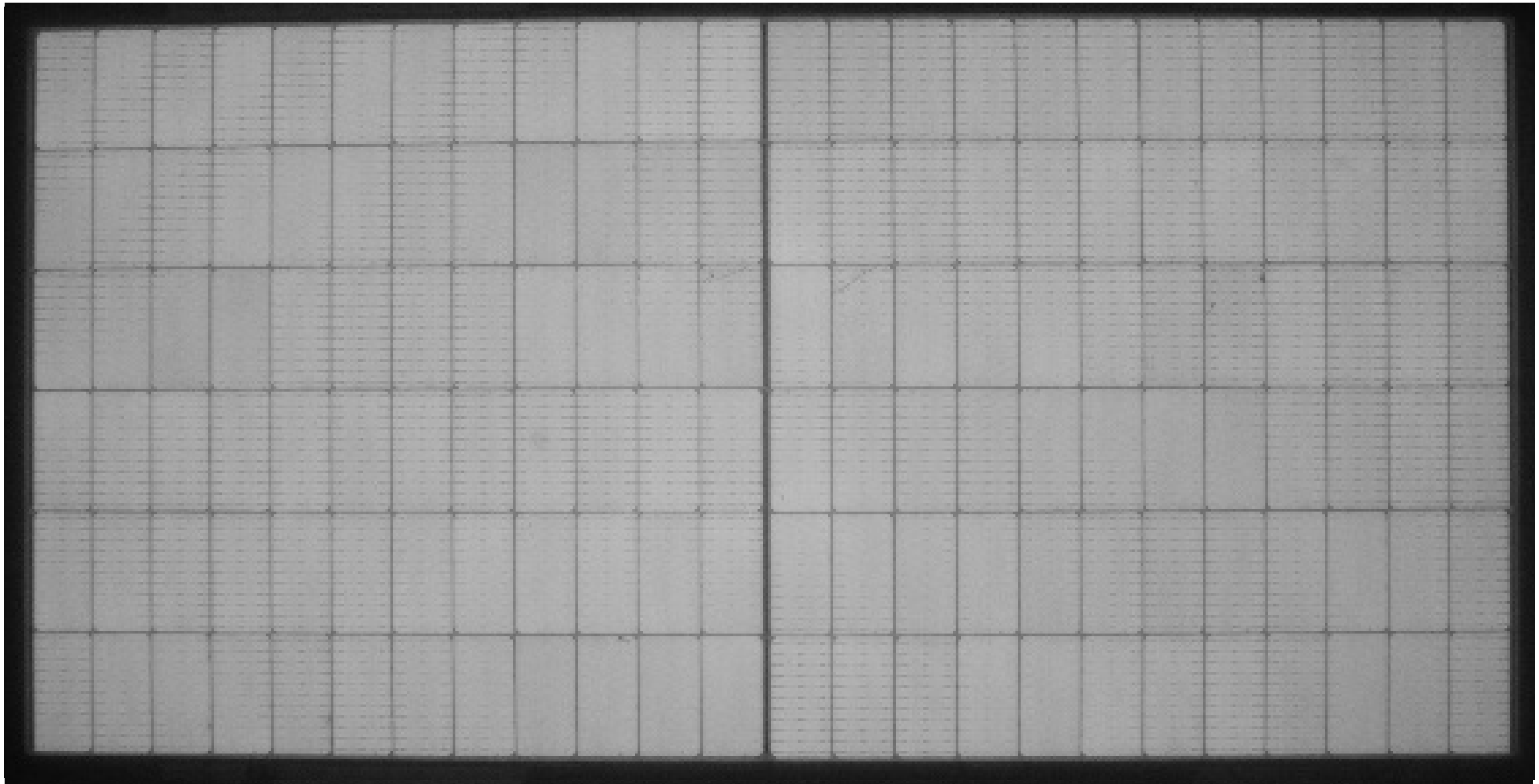

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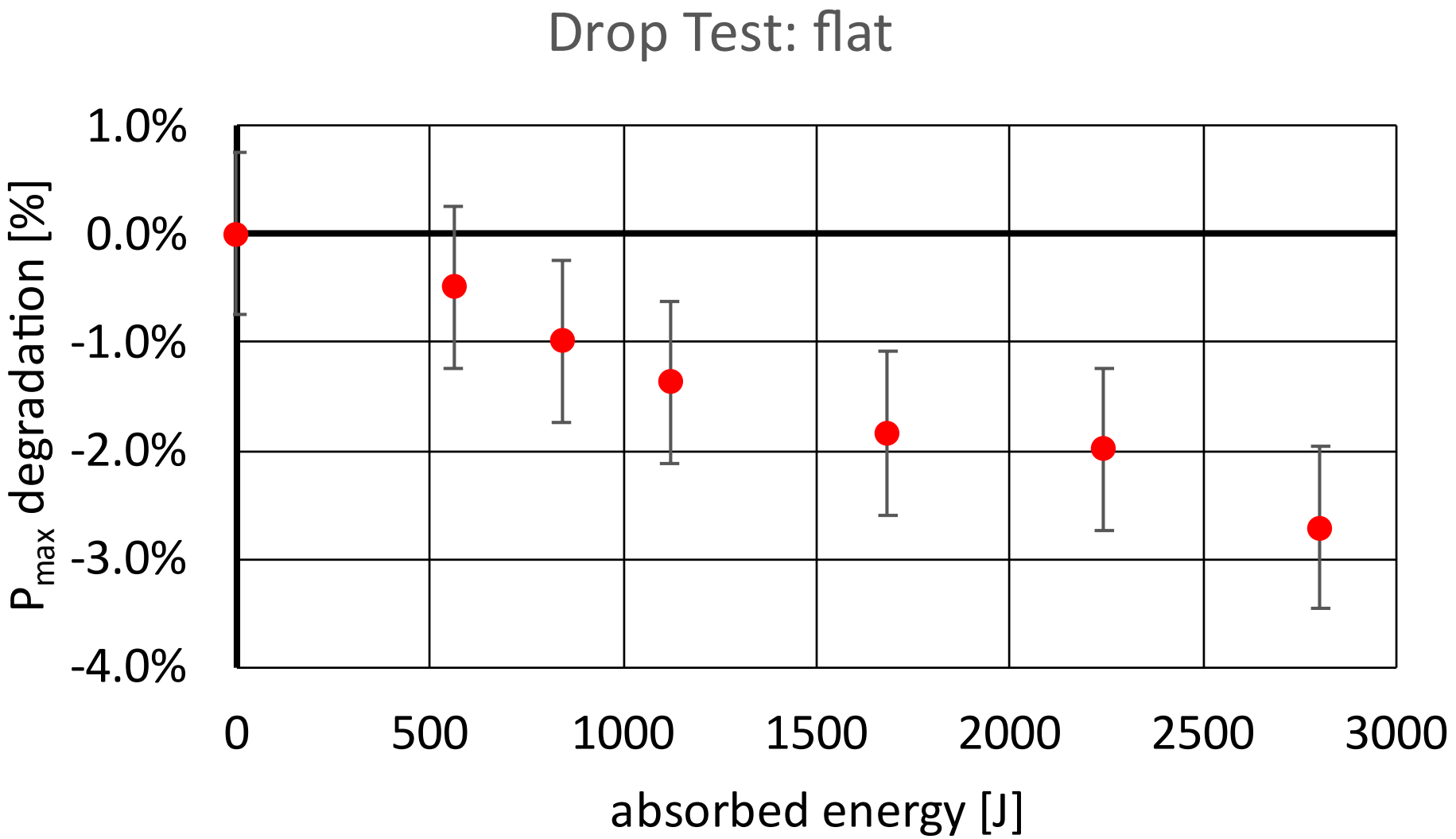

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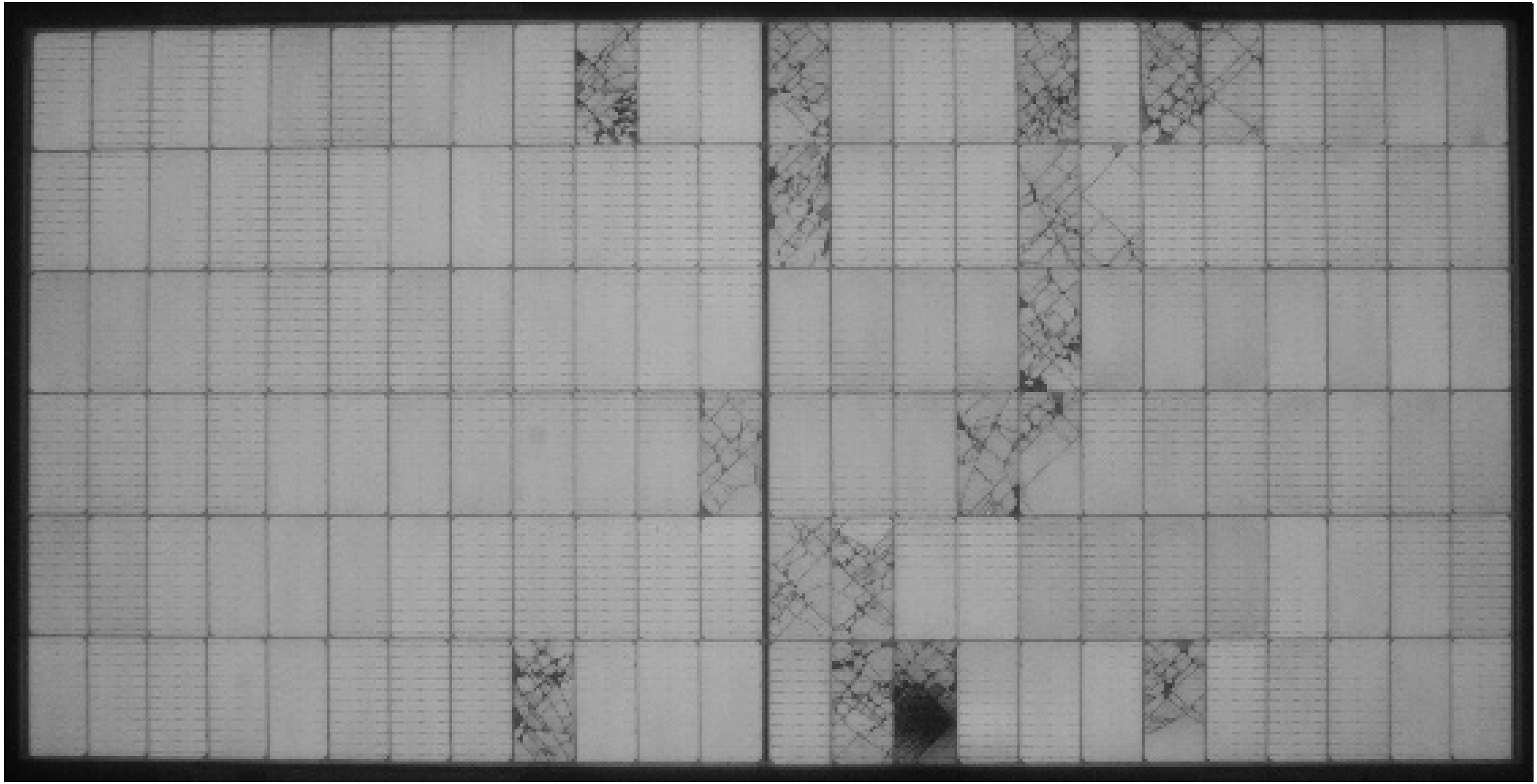


Extended test regime for FPV

What tests would SERIS propose, to address these failure modes?

Stand-alone tests

- ❑ Salt mist
- ❑ Impact of waves
- ❑ Impact of lighting

Sequential stress tests

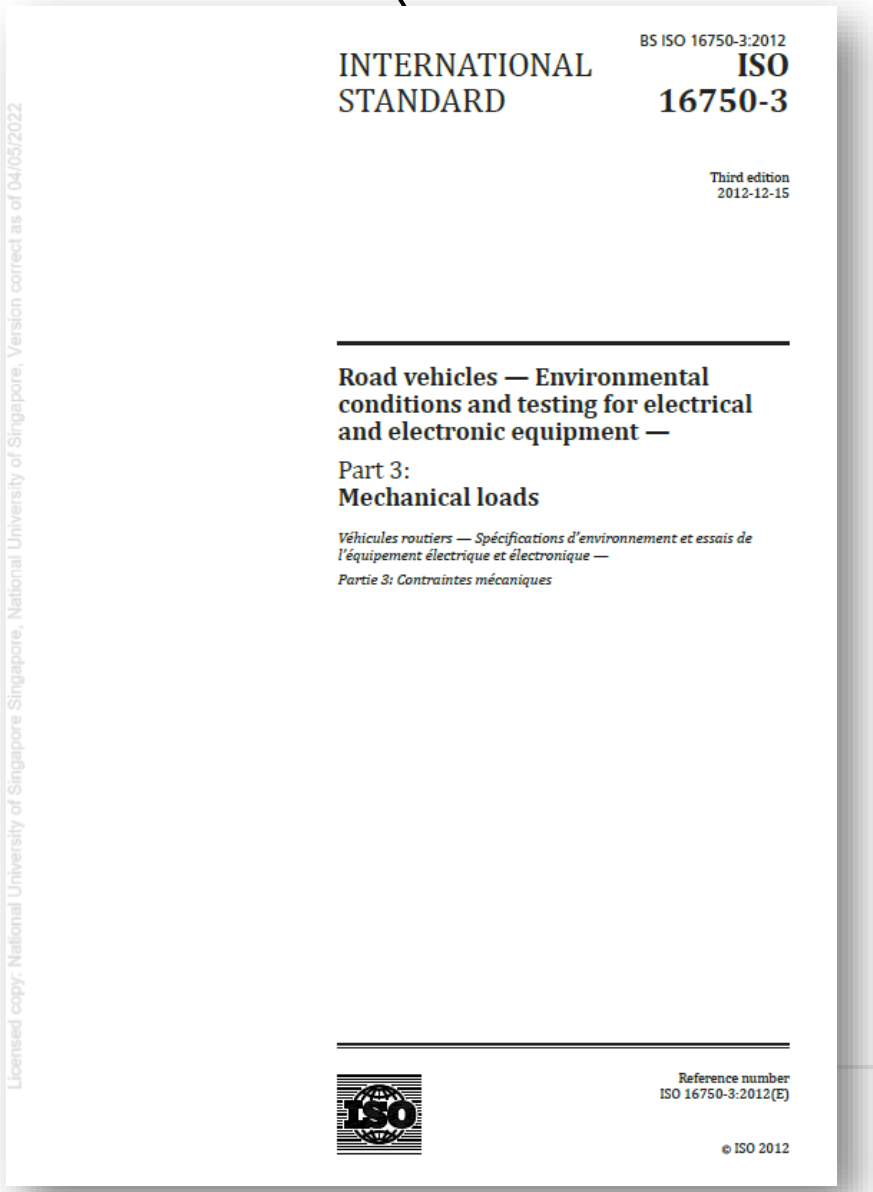
- ❑ Radiation hardening
  - ➢ UV + floating ML
- ❑ Humidity/corrosion resistance
  - ➢ HF + floating ML
  - ➢ UV + HF + floating ML
  - ➢ Same with Salt Mist

Combined stress tests

- ❑ PID + salt mist
  - ➢ Indoor (difficult)
  - ➢ Outdoor (easier but longer)

VIPV (and urban PV): mechanical loads

Vibrational test (ref to ISO standard for vehicles)



BS ISO 16750-3:2012

INTERNATIONAL STANDARD

ISO 16750-3

Third edition
2012-12-15

Road vehicles — Environmental conditions and testing for electrical and electronic equipment —

Part 3:
Mechanical loads

Véhicules routiers — Spécifications d'environnement et essais de l'équipement électrique et électronique —

Partie 3: Contraintes mécaniques

Reference number
ISO 16750-3:2012(E)

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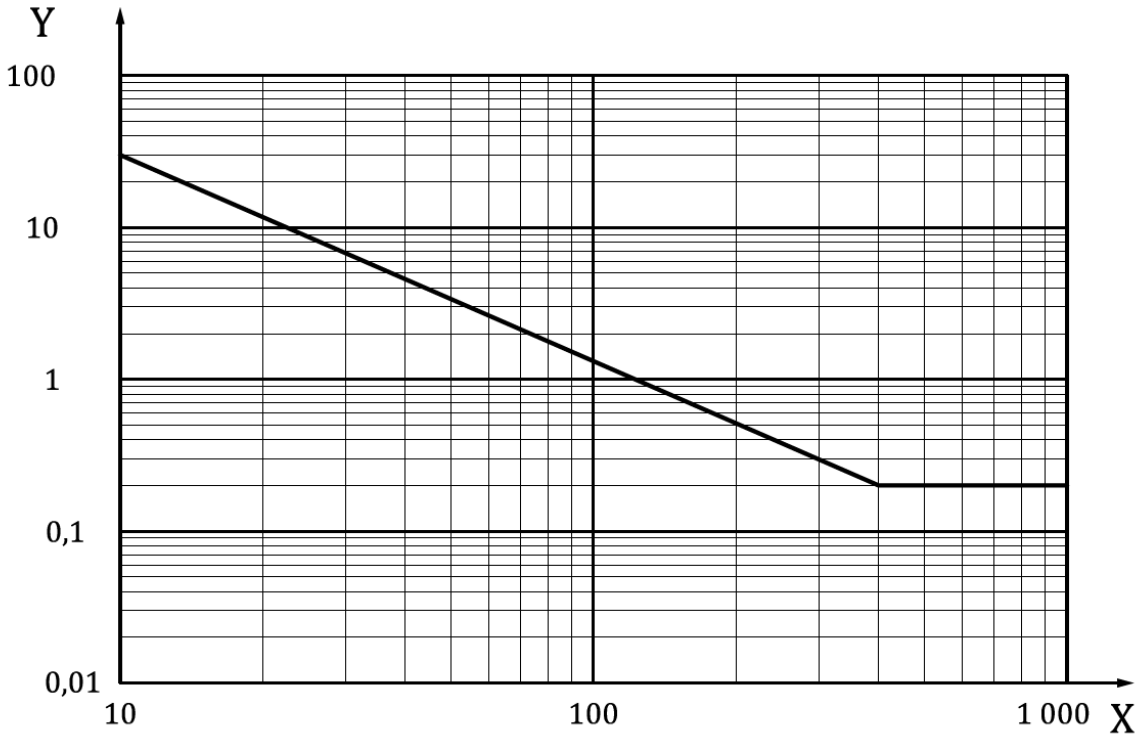
Section 4.1.2.4 (Vibration) Tests for sprung masses

- ❑ From cylinders (sinusoidal) is negligible
- ❑ Vibration is random induced by rough-road driving

X = frequency [Hz]

Y = Power Spectral Density (PSD) $[(m/s^2)^2/Hz]$



Hot spot and BIPV

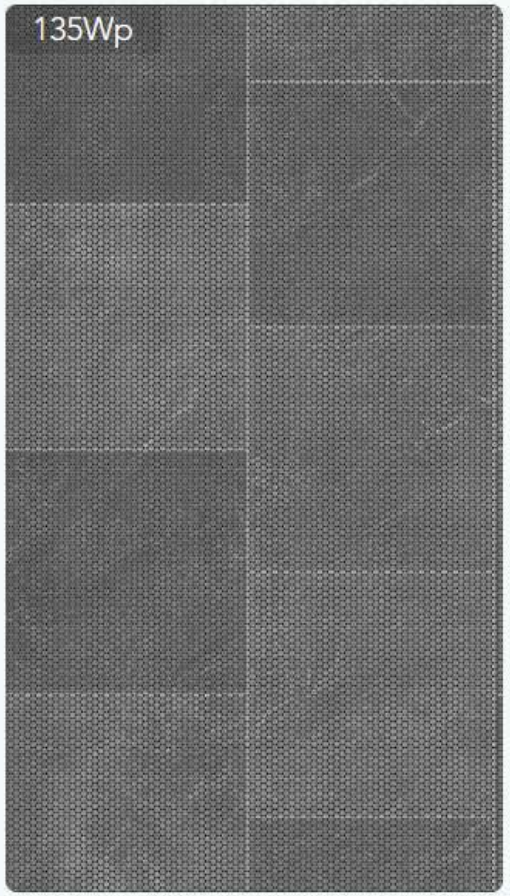
Multi-colour modules should be specifically designed to avoid hot-spot

www.kaleo-solar.ch

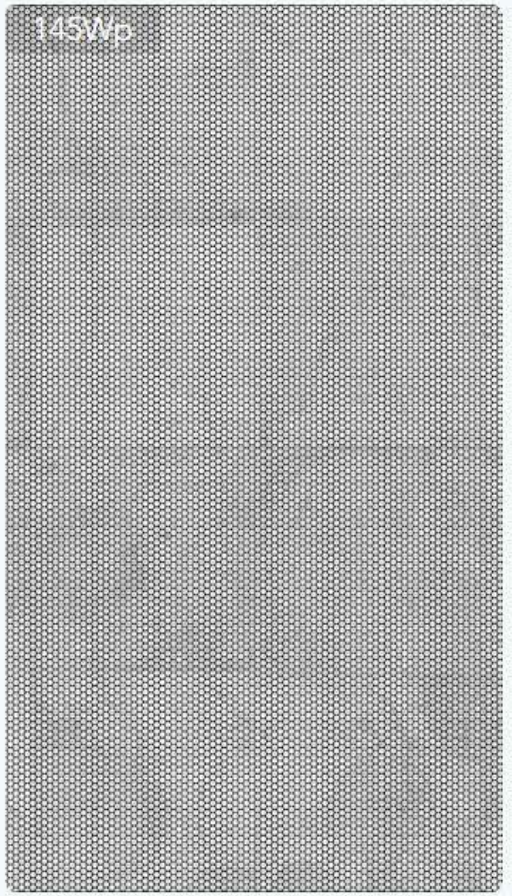
Hot spot and BIPV

Multi-colour modules should be specifically designed to avoid hot-spot

Sapphire



Graytint

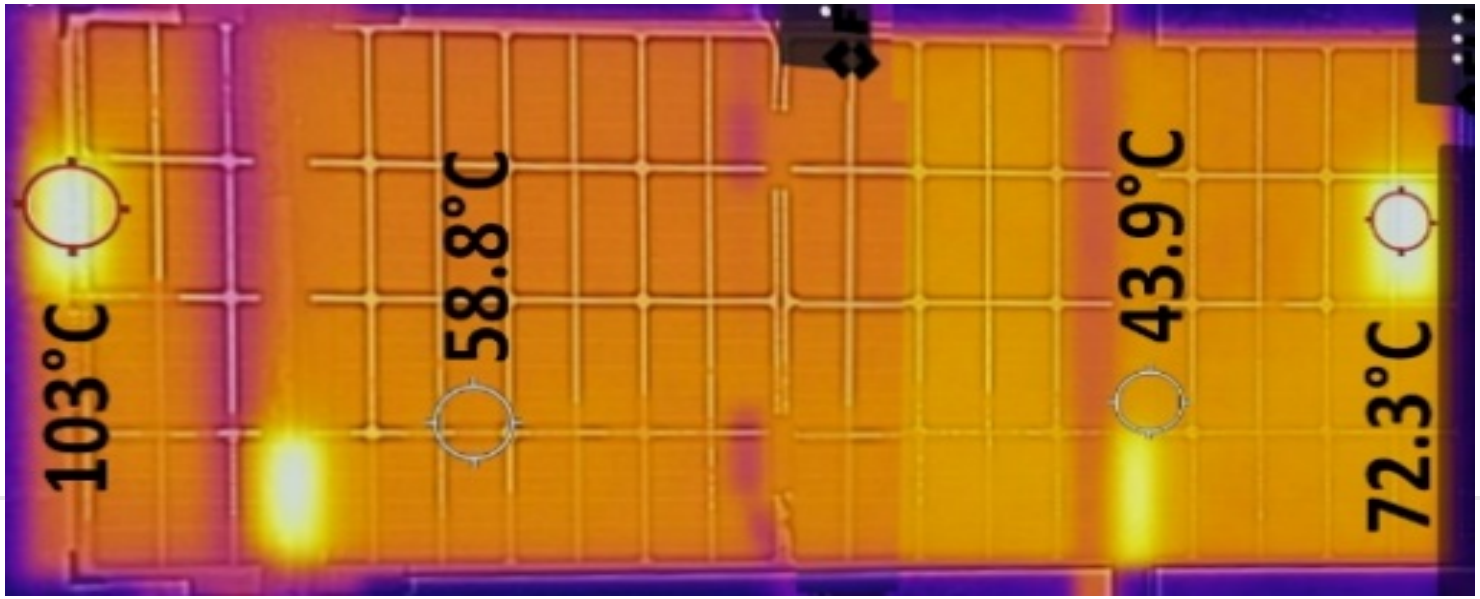


Nightingale

Stoneware

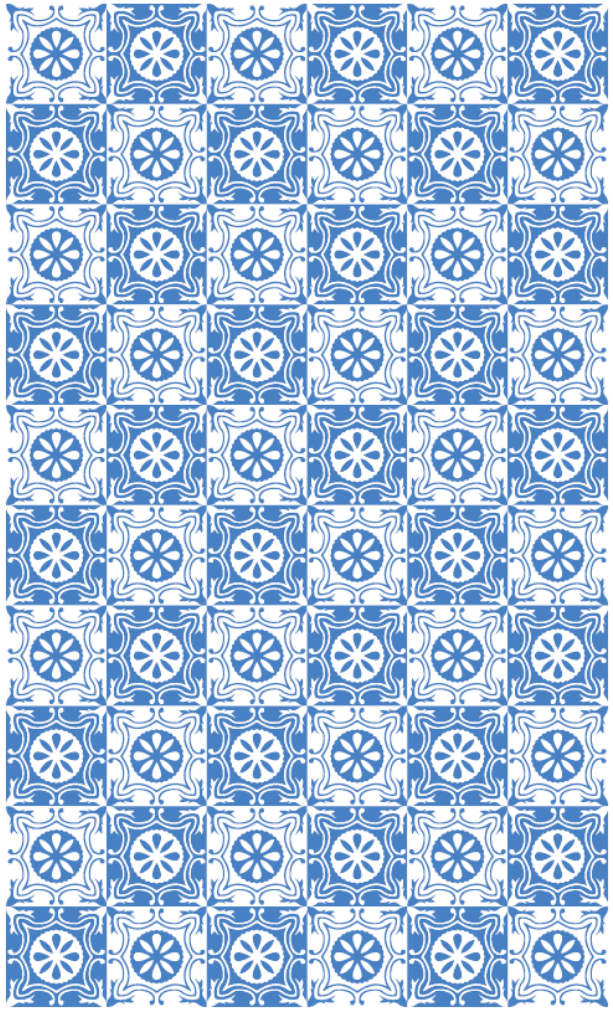
www.pixasolar.com

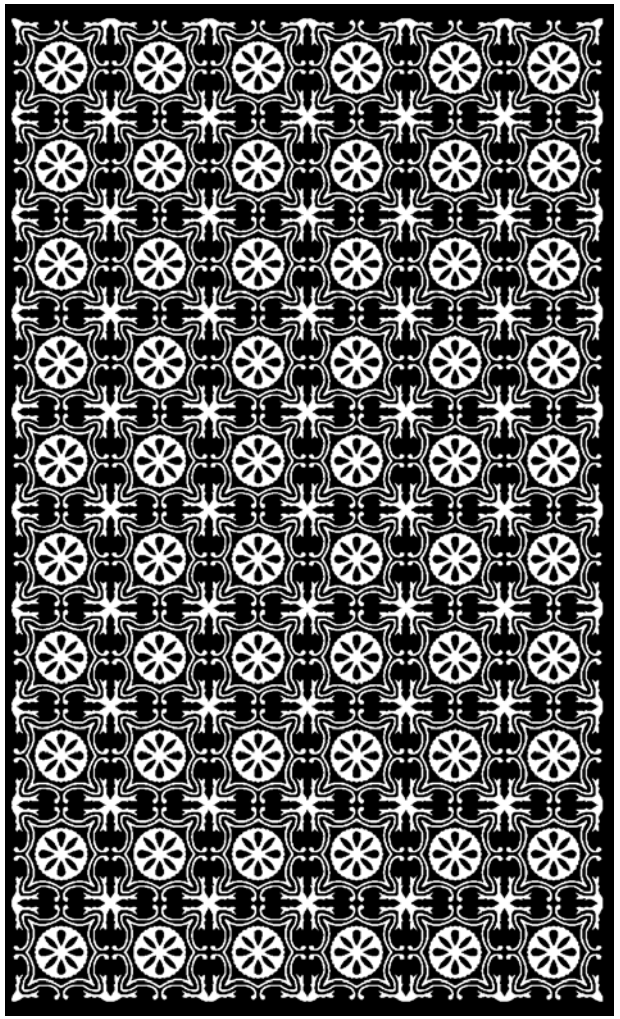
Hot spot and BIPV

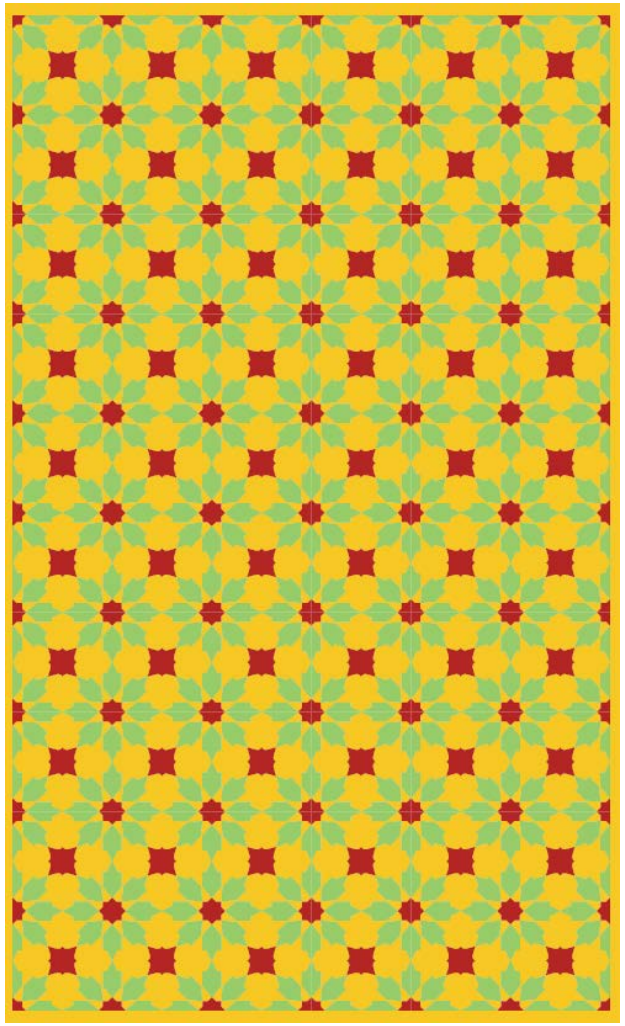


Tested at SERIS, to be presented at:

Repeated pattern: the “Peranakan” module







Presented at SERIS’ booth at:

Other relevant tests that should be explored

Agrivoltaics: mechanical vibrations and soiling

Thank you for your attention!
Contact: Mauro Pravettoni
mauro.pravettoni@nus.edu.sg

More information at www.seris.sg

We are also on: