Degradation Rate Modeling for Encapsulant Discoloration of Photovoltaic Modules Discoloration

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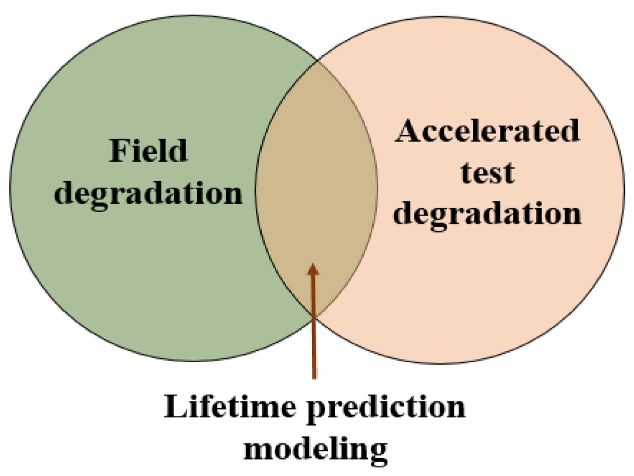
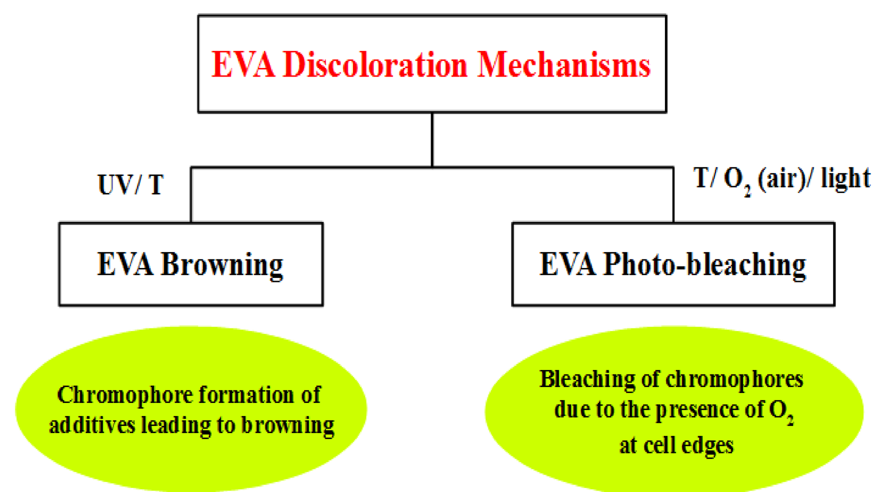
1. INTRODUCTION

- Fielded PV modules experience various degradation modes depending on the climatic conditions, electrical configurations and manufacturing quality → **Reliability concerns**
- Encapsulant discoloration is one of the two most common degradation modes found in the field survey conducted over 56,000 modules in 4 climatic regions of USA [1]
- Improving the module's reliability is the pathway to increase their lifetime of 25+ years and to reduce the levelized cost of energy (LCOE)





Objective: Development of rate dependency model to determine the **acceleration factor** for UV stress testing and **degradation rate** for **PV encapsulant discoloration** in the **climate-specific fields**.

2. METHODOLOGY

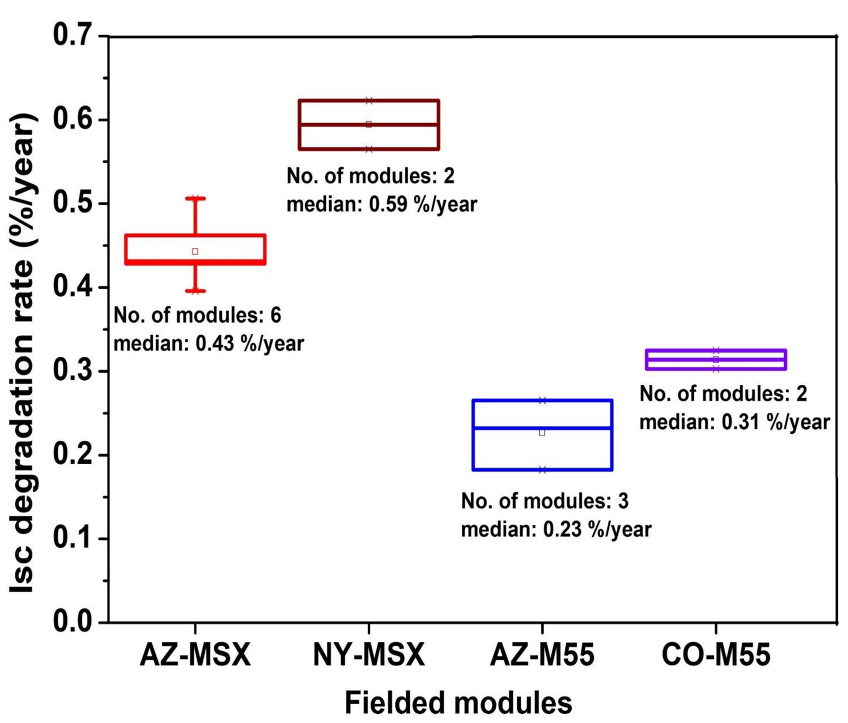
- Hourly weather data are obtained from the Typical Meteorological Year (TMY) database
- **UV irradiance:** 5% of the plane of array (POA) irradiance
- **Module temperature:** Calculated using Sandia model

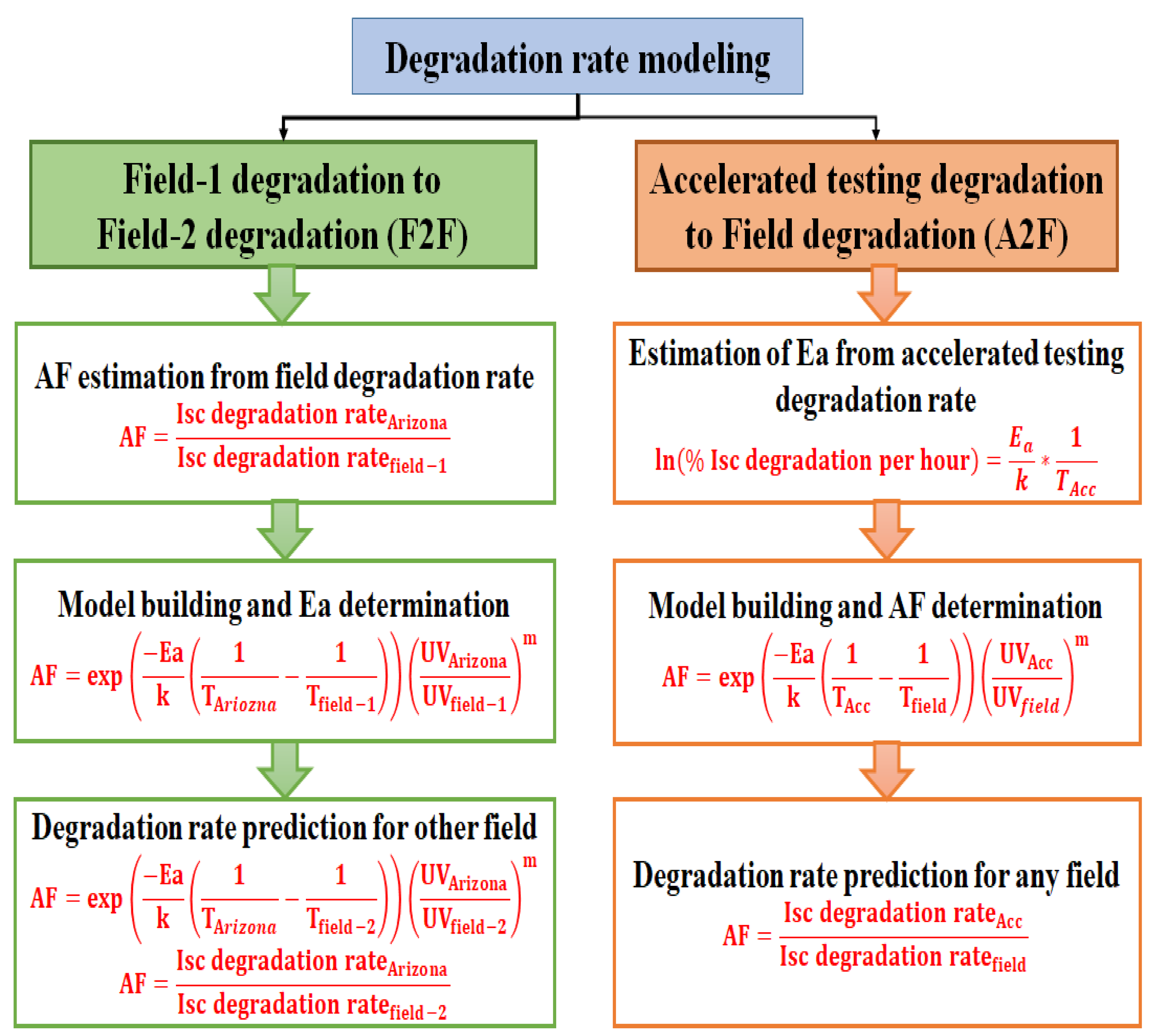
$$T_{mod} = E \cdot e^{a+b(WS)} + T_{amb}$$

- Only the daytime (POA ≥ 40 W/m²) weather data is considered

- **3 different climatic regions:**
  - Hot and Dry: Arizona (AZ)
  - Cold and Dry: New York (NY)
  - Temperate: Colorado (CO)

- **2 different module types:**
  - MSX modules
  - M55 modules





$$\text{Acceleration Factor (AF)} = \frac{\text{Isc degradation rate}_{AZ}}{\text{Isc degradation rate}_{field}}$$

Arrhenius equation: f(T)

$$AF = \exp\left(\frac{-Ea}{k}\left(\frac{1}{T_{AZ}} - \frac{1}{T_{field}}\right)\right)$$

Modified Arrhenius equation: f(T, UV)

$$AF = \exp\left(\frac{-Ea}{k}\left(\frac{1}{T_{AZ}} - \frac{1}{T_{field}}\right)\right)\left(\frac{UV_{AZ}}{UV_{field}}\right)^m$$

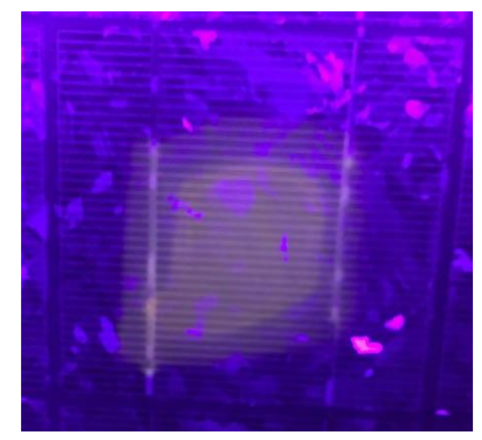
Modified Peck equation: f(T, UV, RH)

$$AF = \exp\left(\frac{-Ea}{k}\left(\frac{1}{T_{AZ}} - \frac{1}{T_{field}}\right)\right)\left(\frac{UV_{AZ}}{UV_{field}}\right)^m\left(\frac{RH_{AZ}}{RH_{field}}\right)^m$$

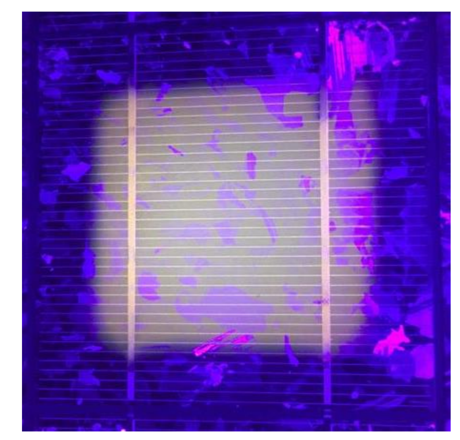
3. TESTING AND PHYSICAL MODELING RESULTS

Activation energy determination

Outdoor field degradation



AZ module (21 years)



NY module (18 years)

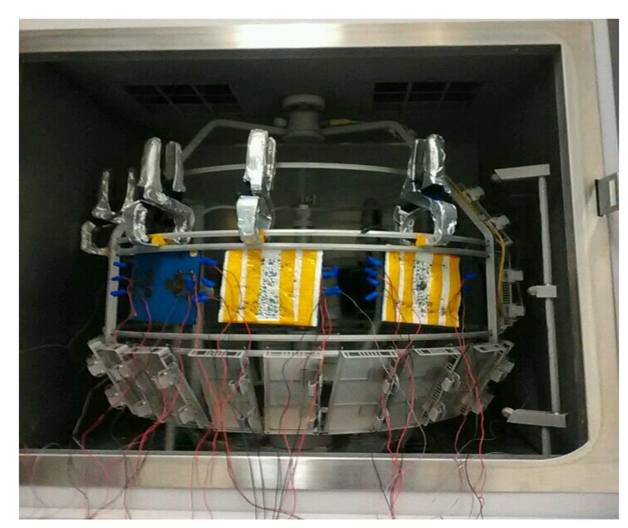
Lower browning in AZ module → higher oxygen bleaching due to higher operating temperature

		Ea (eV)		
F2F approach	AF_G	Arrhenius model	Modified Arrhenius model	Modified Peck model
AZ | NY	0.74	-0.15	0.29	1.11
AZ | CO	0.73	-0.16	0.31	1.83

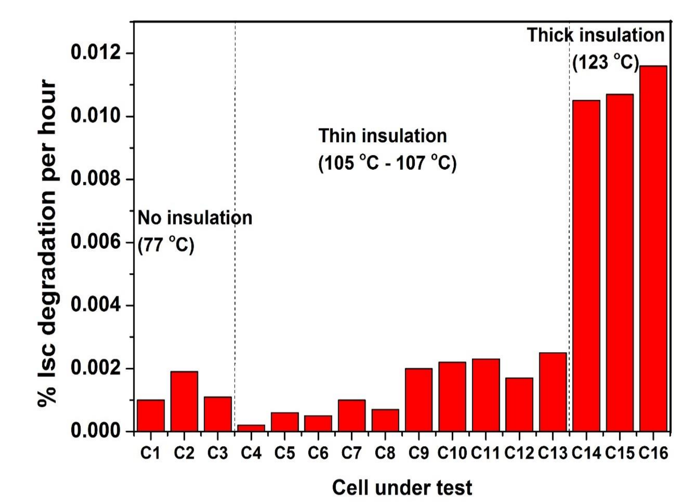
Modified Arrhenius model provides better estimation of Ea for encapsulant browning

Indoor accelerated UV testing degradation

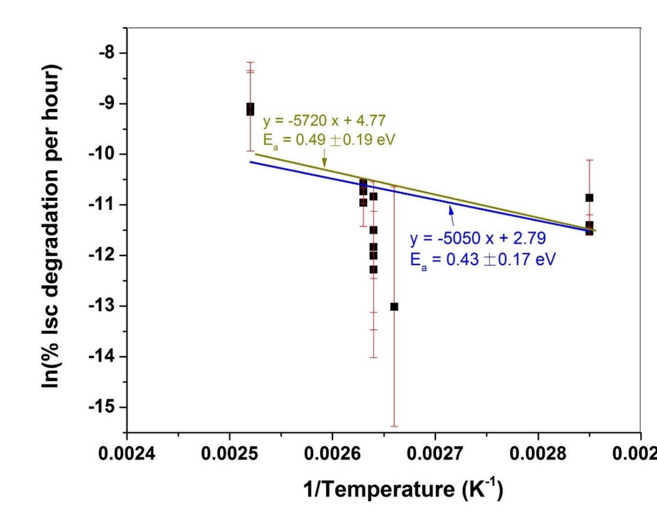
- **Unique merits of our testing approach:**
  - 3 module temperatures in one chamber
  - 6 cells (backskin cut) per module per temperature (more data points per temperature for statistical confidence)
  - Activation energy and acceleration factor are determined based on Isc degradation, not based on Pmax degradation because Pmax may be influenced by other degradation modes



Atlas weathering chamber



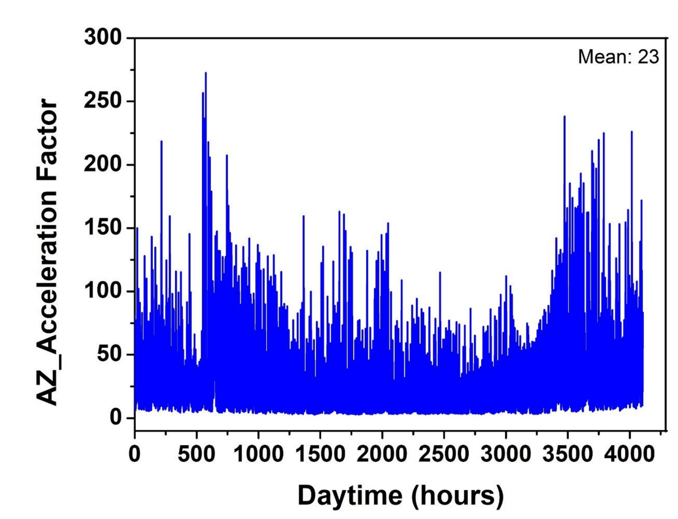
Cell Isc degradation under UV testing



Arrhenius model for Ea estimation

Degradation rate prediction

For Arizona climate (Hot-Dry)

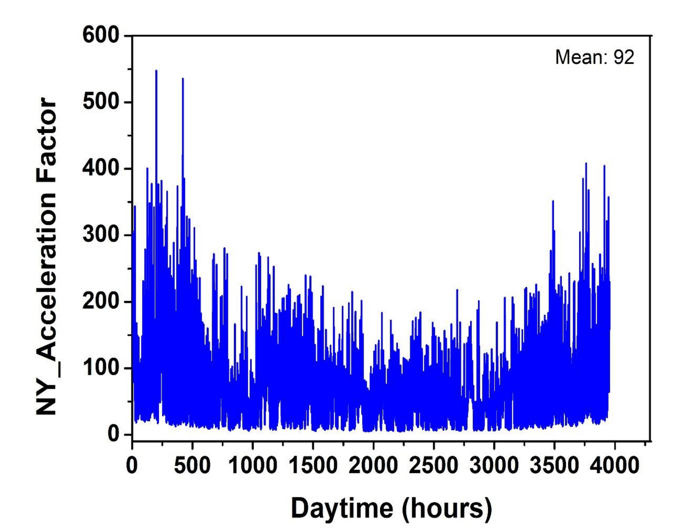


Predicted Isc deg rate: **0.37%/year**

<14% of field measured value (0.43%/ year)

	AZ	NY
UV irradiance (W/m²)	27.5	18.7
T_{mod} (K)	314	294

For New York climate (Cold-Dry)



Predicted Isc deg rate: **0.29%/year**

4. CONCLUSIONS

- The physical modelling approach developed is able to closely predict the Isc degradation rate in glass/backsheet specific modules deployed in AZ and NY field
- It can be extended to other construction, manufacturer and climate-type.
- This work will be instrumental in designing the accelerated stress testing to study the long-term reliability issues associated with polymeric encapsulant and hence evaluating the fielded module's electrical performance and service lifetime.

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Reference

[1] S. Tatapudi, et al., "Defect and Safety Inspection of 6 PV Technologies from 56,000 Modules Representing 257,000 Modules in 4 Climatic Regions of the United States," 43rd IEEE PVSC, Portland, pp. 1747–1751, 2016.

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