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What service time for PV modules ?

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Switzerland 1982

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I. Introduction

Presentation of CEA - INES

Solar activities started at CEA in 1978 in Cadarache (close to Aix-en-Provence)

INES creation in 2005 in Bourget-du-Lac (close to Chambéry).
Now:

- 450 persons
- 70 patents/year
- 200 industrial partners
- 60 M€ annual budget

Definition

“The lifetime of a photovoltaic module can be defined as a point in time when the module is no longer acceptable for any reason such as safety, appearance, a catastrophic event, or when the output power has fallen below a minimum acceptable value.”

C.R. Osterwald, NREL (National Renewable Energy Laboratory, USA)

History of Accelerated and Qualification Testing of Terrestrial Photovoltaic Modules: A Literature Review
C. R. Osterwald and T. J. McMahon
National Renewable Energy Laboratory, Golden, CO, USA

A system is stopped when its revenue is lower than the maintenance costs
~~Lifetime~~ ≈ Service time
The commonly accepted service time is 30 years.

Service time studies

- Need for better prediction:
  - Increase of confidence in PV products
  - Decrease of the risk for PV players

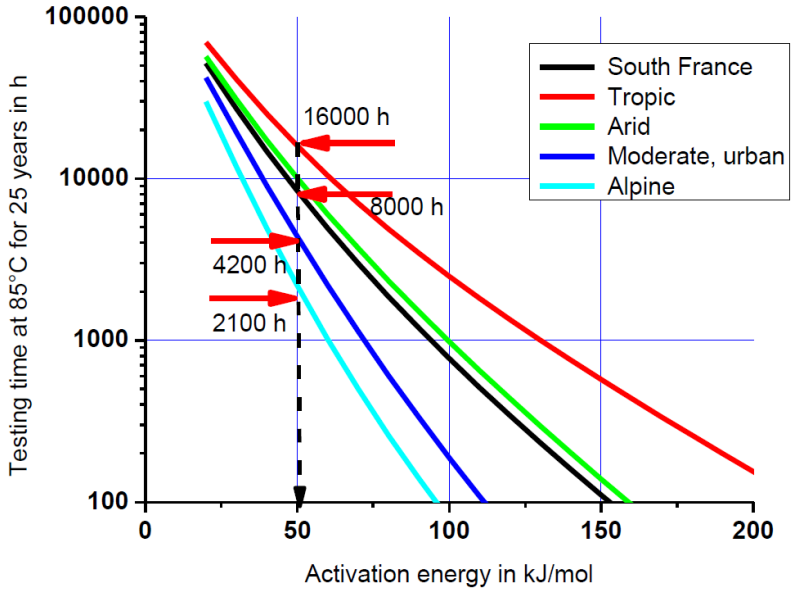
- Means:
  - Accelerated stress tests
    - Normative tests
    - Time-to-failure
  - Long term observations

II. Accelerated stress tests

Standard accelerated stress tests

Main tests: UV light, Damp heat (85°C, 85% RH), Thermal Cycles (-40°C, +85°C), Humidity freeze (-40°C, 85% RH), ...
Goal: test all effects separately to enlighten degradation mechanisms and modelling ageing

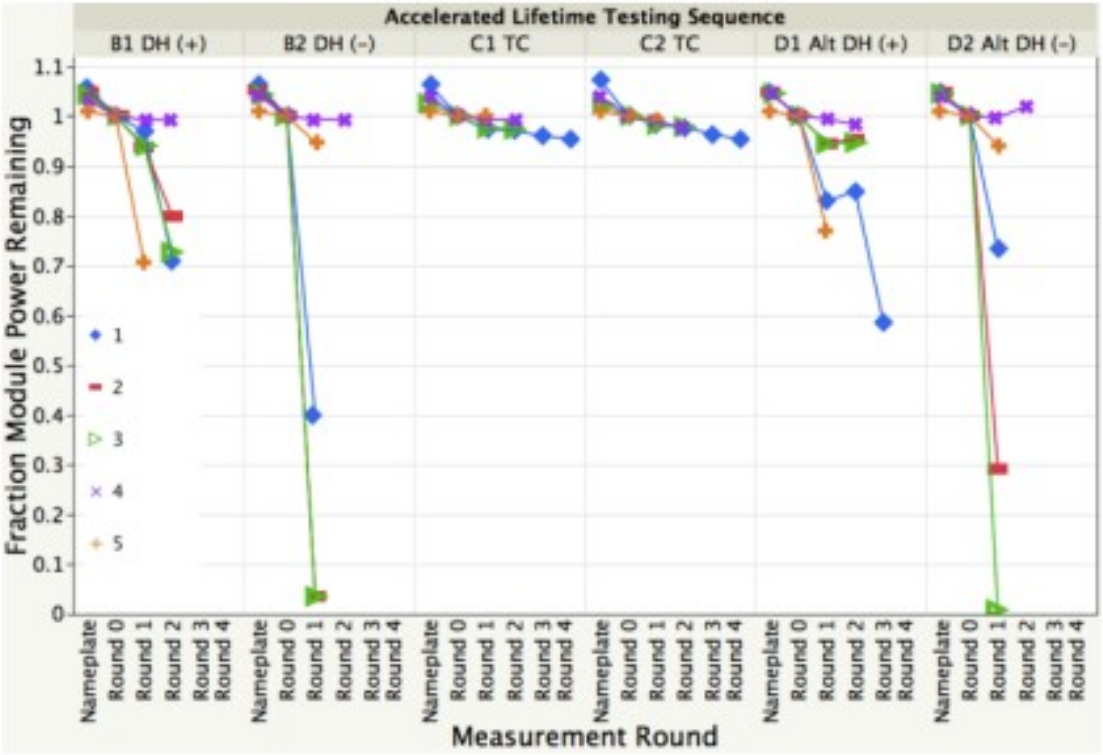
Temperature	$+ A\,\Delta t_i\ \exp[-E_A/RT_i]$
Humidity	$+ B\,\Delta t_i\, f(rh)_i \exp[-E_B/RT_i]$
UV-radiation	$+ C\,\Delta t_i\, I^n_i \exp[-E_C/RT_i]$
Temperature cycles	$+ D\,\Delta t_i\, f(\Delta T)_i \exp[-E_D/RTi]$
Potential-induced Deg.	$+ E\,\Delta t_i\ f(P)_i\ \mathbf{fp(rh)}_i \exp[-E_E/RT_i]$
Salt	$+ F\,\Delta t_i\ f(S)_i\ \mathbf{fp\ (rh)}_i \exp[-E_F/RT_i]$



Michael Köhl, Real loads worldwide, Fraunhofer ISE

Time-to-failure protocol (NREL)

Applied to c-Si



Observations:

- DH: metallization corrosion, SiN degradation
- TC: cells cracks
- Alt TC-DH: cells shunts, backsheet cracks

Limits of accelerated stress tests

Standards originally designed to model 20 years of operation, but theses tests appears to be only good to eliminate unreliable modules (infant mortality).

Difficulty to model reality by combinations of stress tests results.

Stress test do not always represent a real long period:

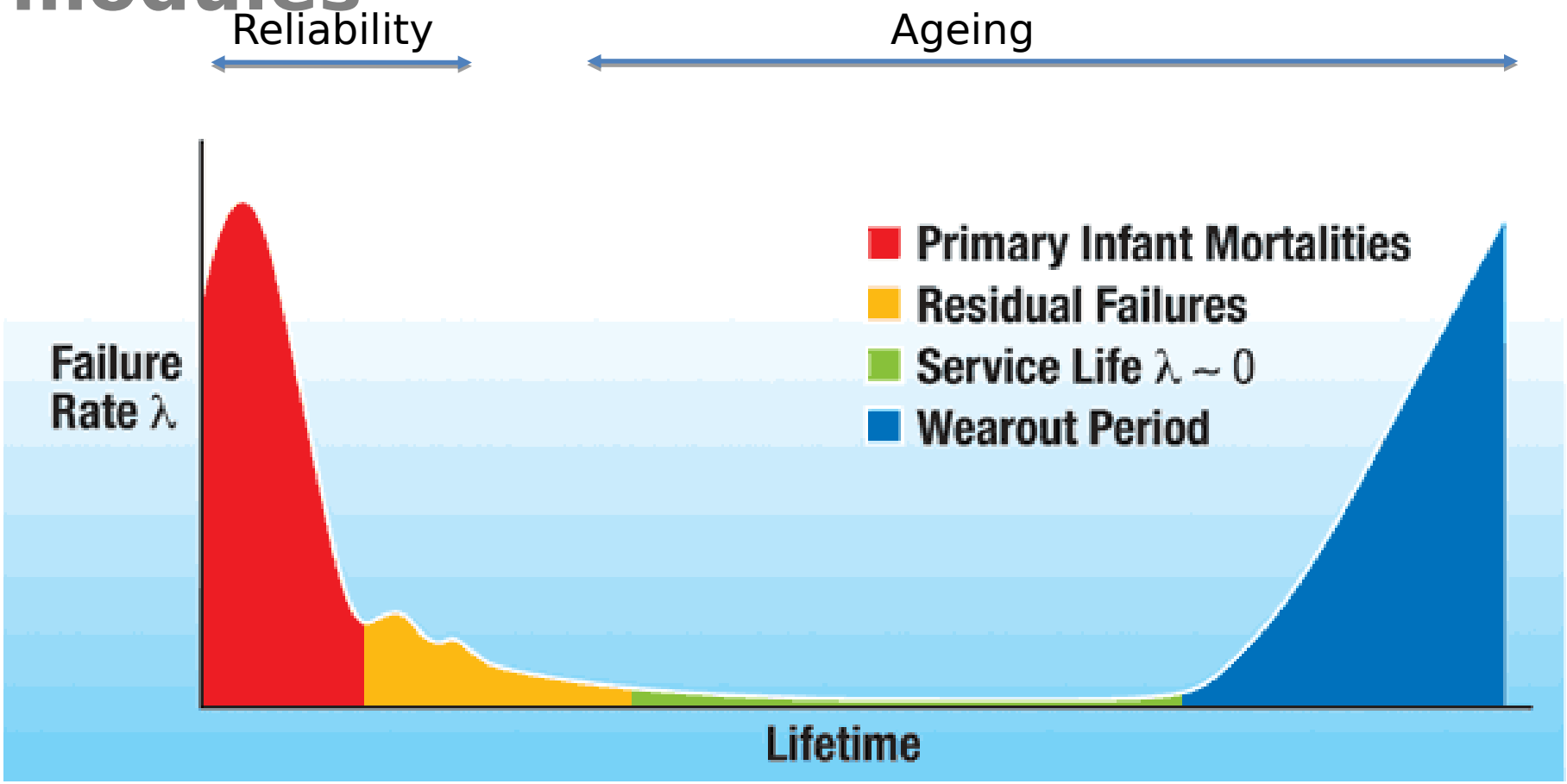
85°C 10 min

37°C 23 days

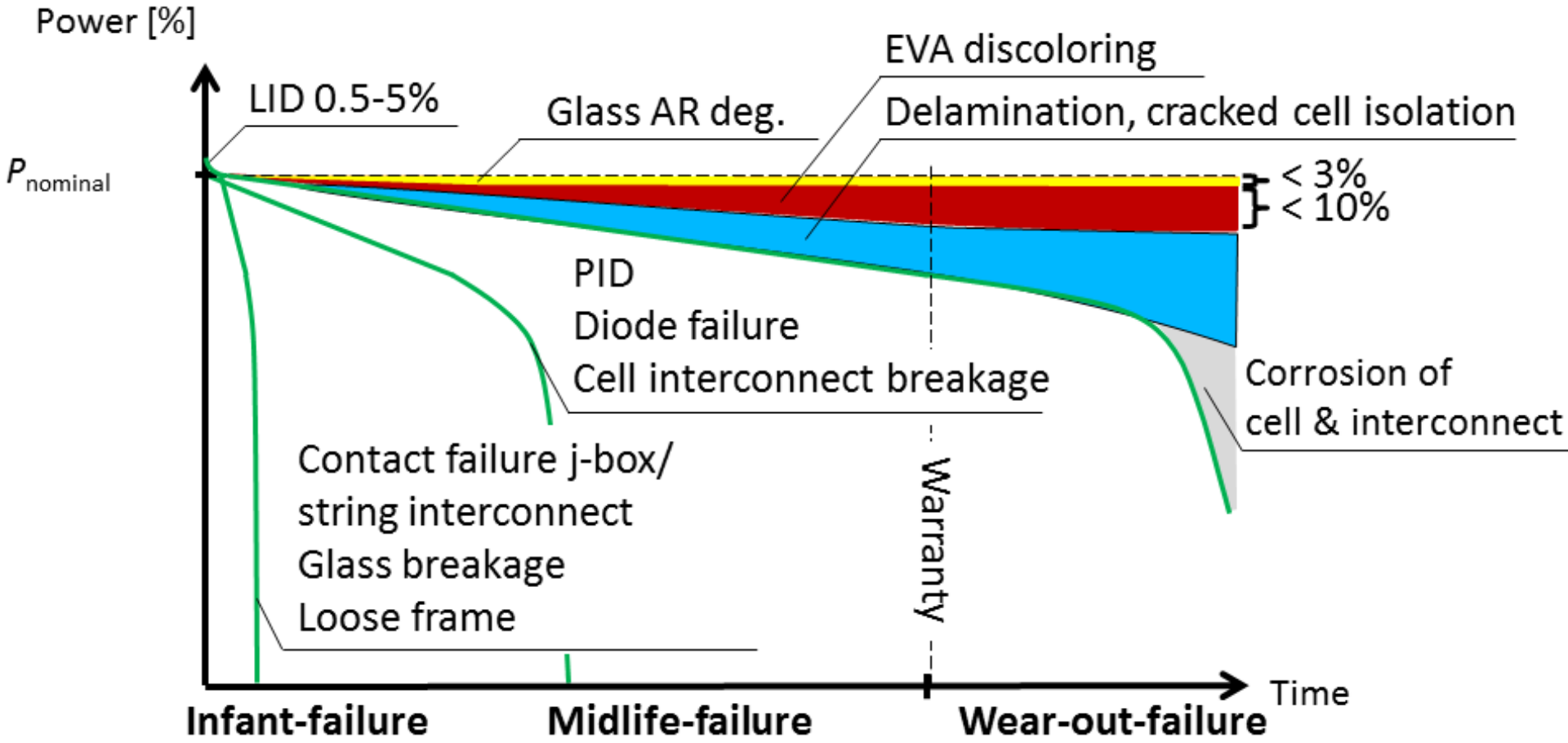
20°C 2 years

III. Long term observations

Bath curve of reliability for PV modules

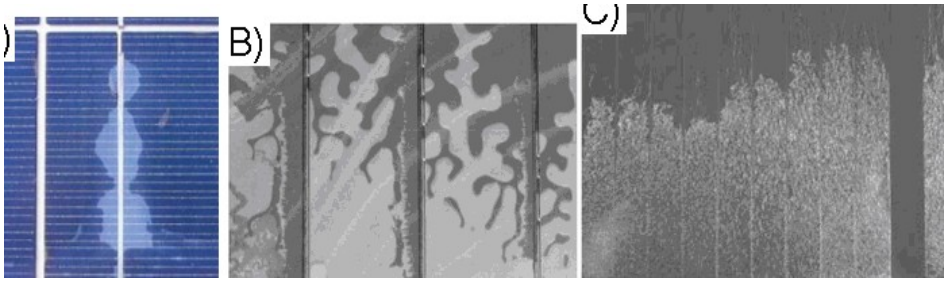


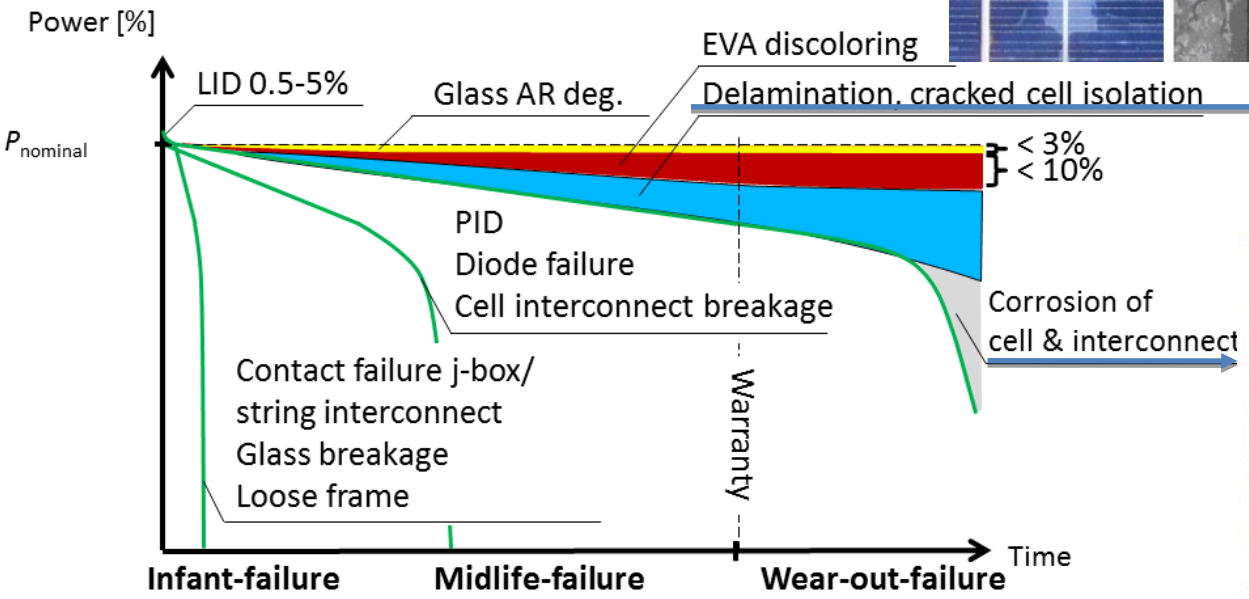
Description of some failures causes



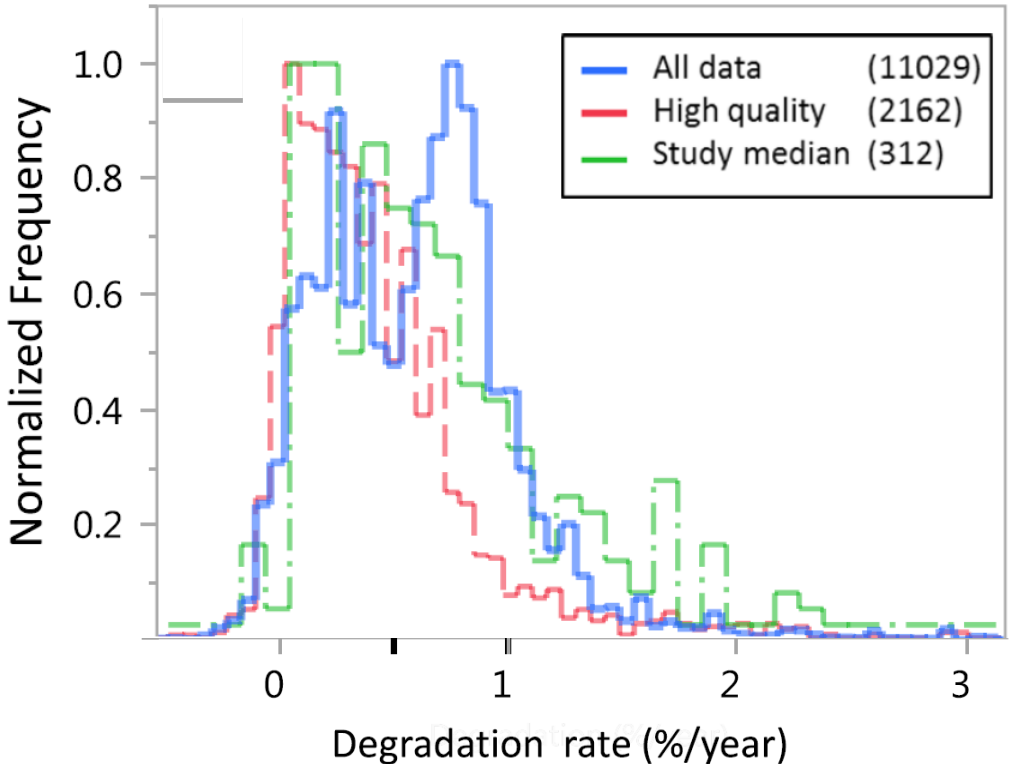
Description of some failures causes

Different delamination cases. A) c-Si. B) CdTe. C) a-Si





Degradation rates review (NREL)



Histograms of all data, high quality data and the median per study and system presented as the normalized frequency. Cumulative distribution functions for high-quality x-Si systems and modules.

Degradation rates review (NREL)

Table I. Summary of the median and mean degradation rate and the number of data points for various subsets of the aggregated data. 2+ indicates study types using two or more measurements and excludes systems with known start-up issues.

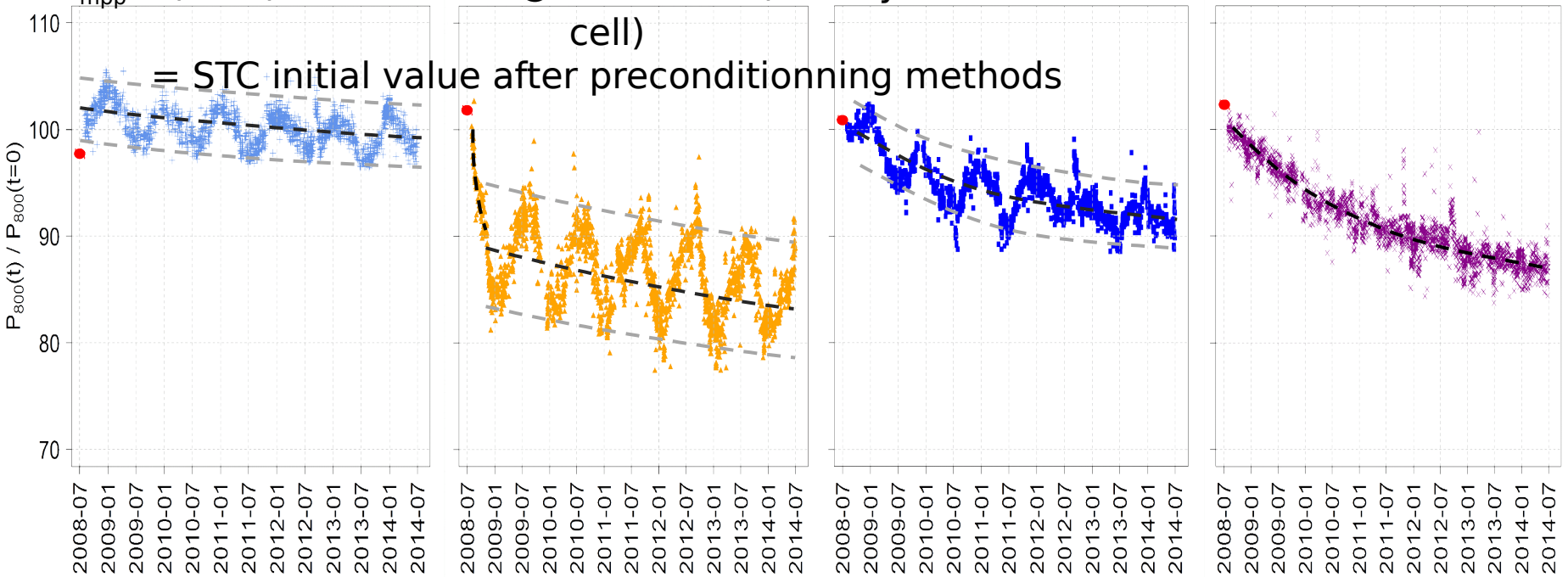
Technology	Study type	System/Module	Median	Mean	Data points
All data	All	All	0.90	0.93	11 029
x-Si	All	All	0.90	0.91	10 572
Thin-film	All	All	1.15	1.38	455
All	Median per study and system	All	0.82	1.09	312
All	2+ measurements	All	0.46	0.69	2792
All	1, outdoor IV	All	1.08	1.06	7238
All	1, indoor IV	All	0.64	0.77	963
All	High quality studies	All	0.49	0.66	2161
x-Si	Median per study and system	Modules	0.67	0.91	127
x-Si	Median per study and system	Systems	0.69	0.79	108
x-Si	High quality, all	Modules	0.40	0.51	1552
x-Si	High quality, all	Systems	0.64	0.81	384
x-Si	High quality, Median per study and system	Modules	0.55	0.59	61
x-Si	High quality, Median per study and system	Systems	0.61	0.69	71
x-Si	High quality, desert	All	0.71	1.19	42
x-Si	High quality, hot and humid	All	0.60	0.80	683
x-Si	High quality, moderate	All	0.42	0.57	1396
x-Si	High quality, snow	All	0.35	0.62	39

Performance studies at CEA

Example of results of 4 modules for 6 years of monitoring

P_{mpp}=f(time) at 800W/m² @Cadarache (ref: crystalline silicon cell)

= STC initial value after preconditionning methods



Si polycrystalline

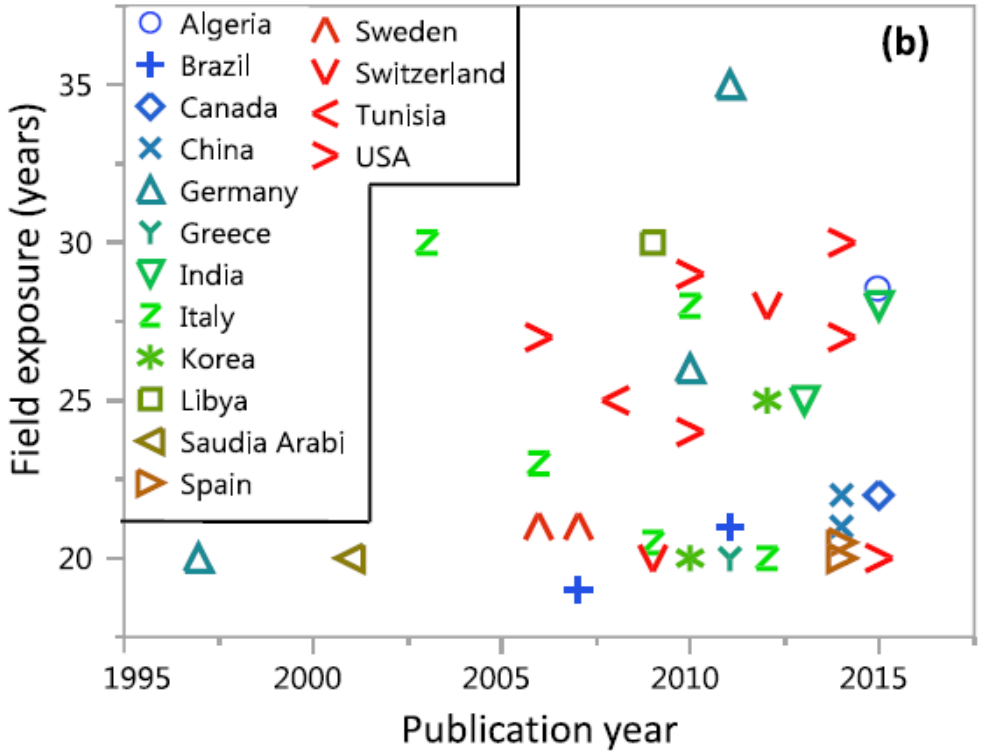
- 0.51%/year
(6 years loss = -3.1%)

Si amorphous
-10.7% in the first 3 months
then **-1.2%/year**
(6 years loss = -17%)

CIGS
-2.5%/year in the first 2 years then
-0.9%/year
(6 years loss = -8.6%)

CdTe
-3%/year in the first 3 years
then **-1.4%/year**
(6 years loss = -13%)

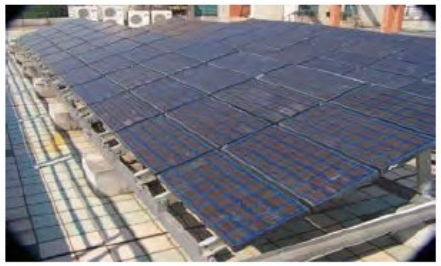
Degradation rates review (NREL)



Switzerland 1982

Japan 1983

USA 1984

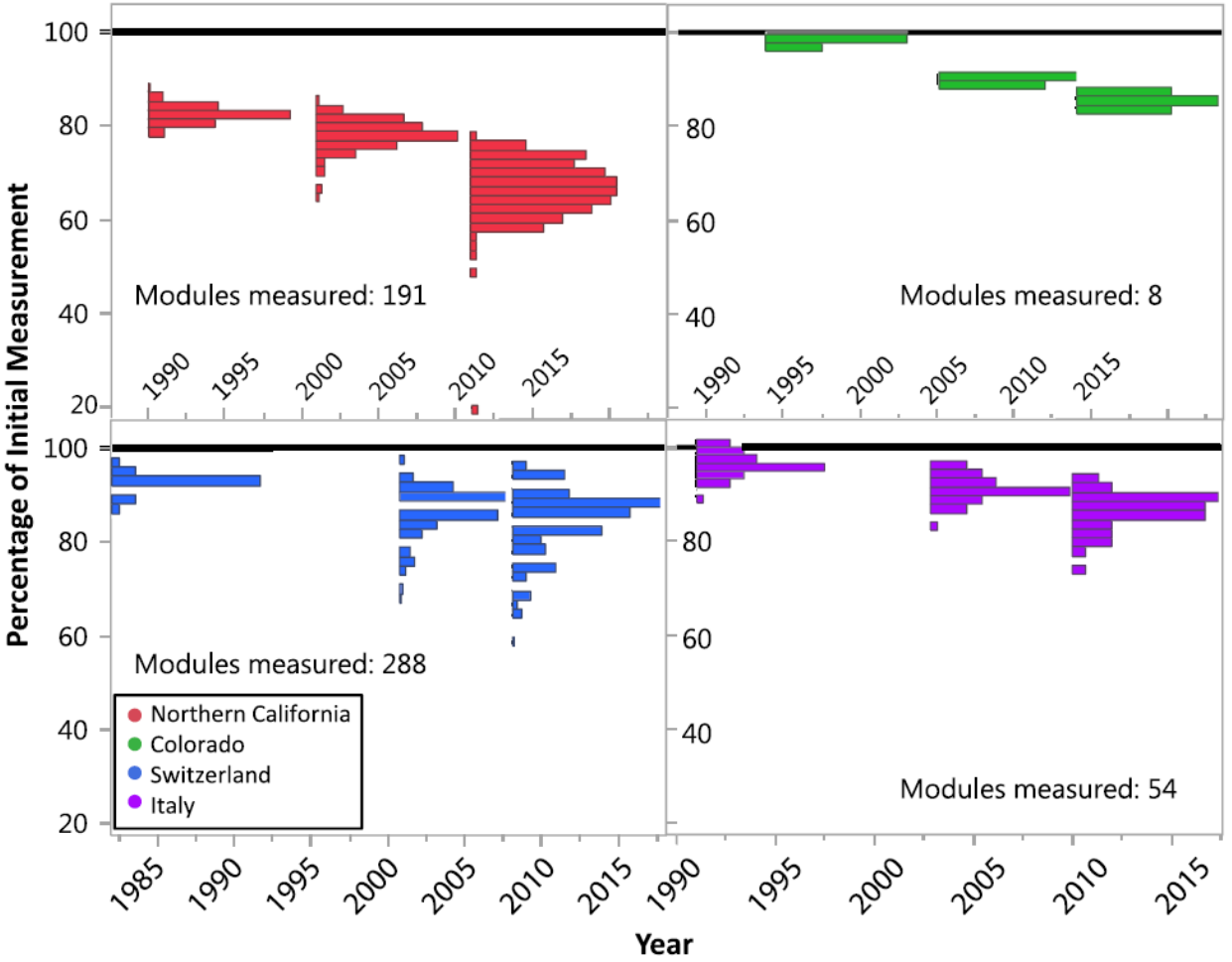


China 1985

Degradation rates review (NREL)

Evolution of the distribution of modules power over 20 years

 System power is driven by the power of the weakest modules!



V. Conclusion

Conclusion

- Commonly accepted service time: 30 years.
- Accelerated stress tests useful for:
  - Reliability assessment
  - Degradation mechanisms study (very costly to be relevant)
- Long term observations useful for:
  - Increase confidence in the service time of PV products
  - Production evaluation throughout the service time
  - Degradation mechanisms study (long and very costly to be relevant)