Arizona State University Photovoltaic Reliability Laboratory

Ira A. Fulton Schools of Engineering, Arizona State University

Solar PV Module Durability Testing

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Presentation Outline

- Difference between durability and reliability
- Importance of durability
- Outdoor durability evaluation
- Indoor durability evaluation
- Summary

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Difference between durability and reliability

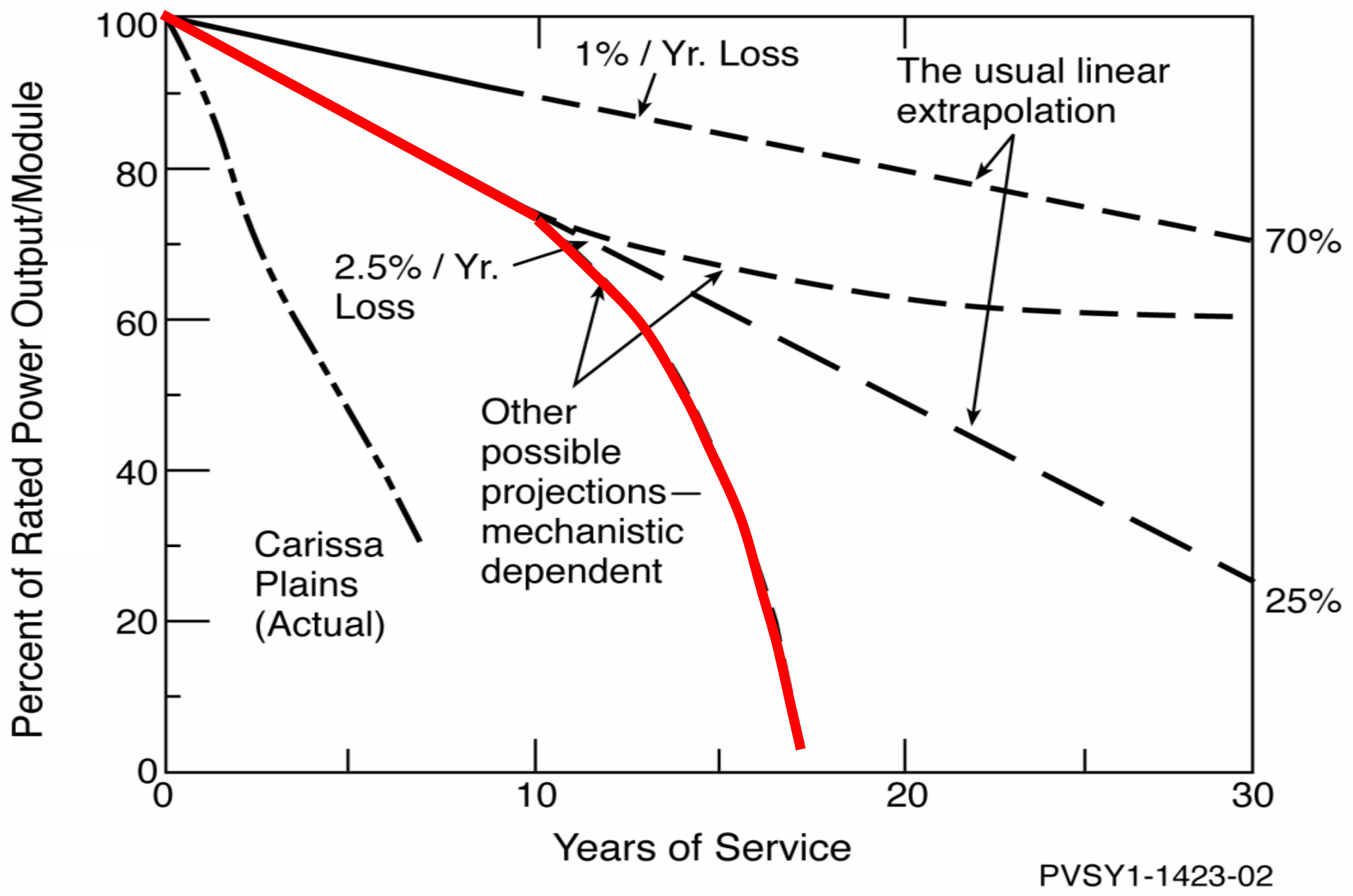
kWh is dictated by durability loss and reliability loss

Durability loss = Degradation rate below warranty rate

Reliability loss = Degradation rate above warranty rate

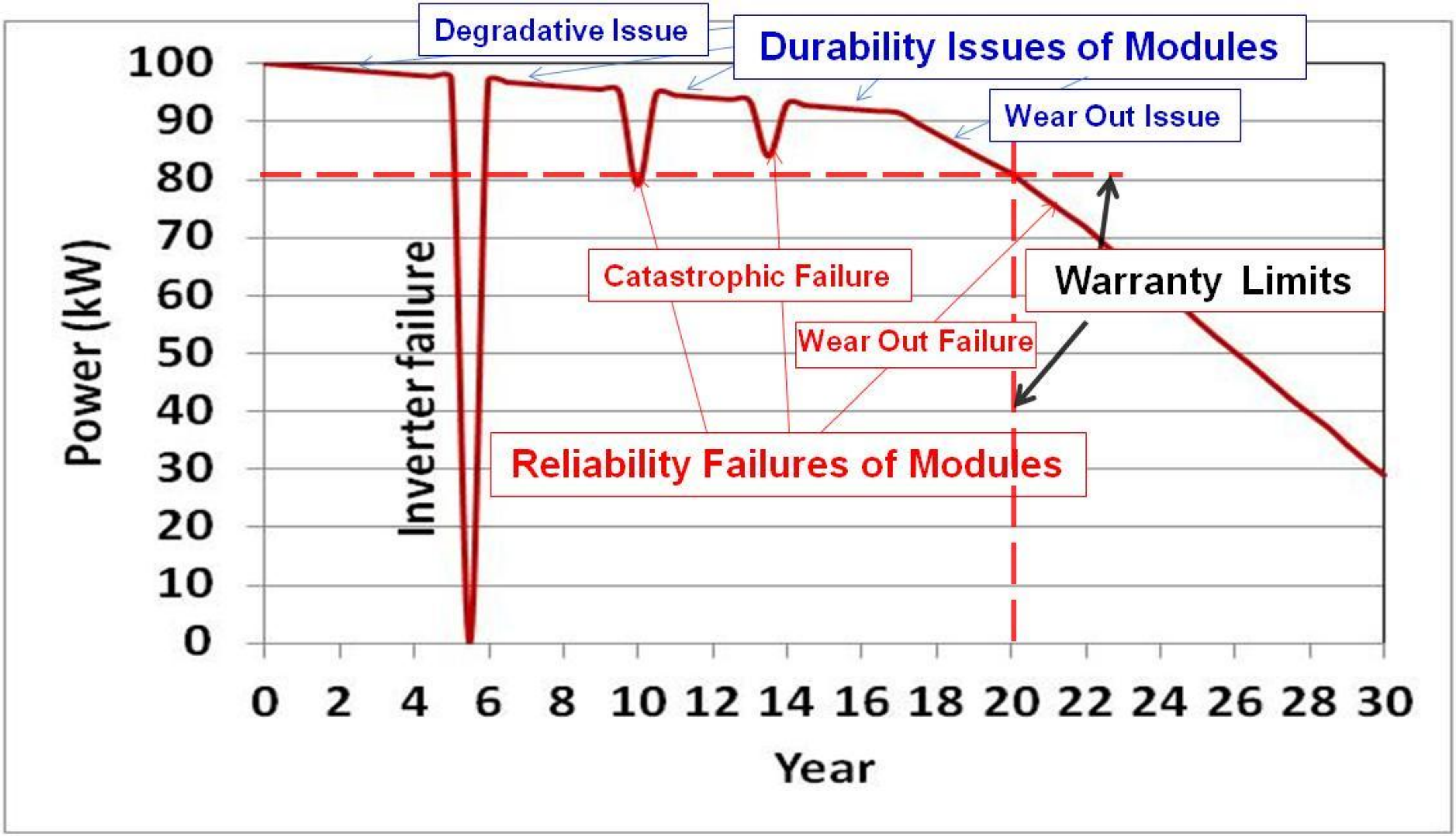
Note: Safety failed modules shall be replaced and these modules should be excluded from the degradation rate calculations

Possible degradation trends



A.W. Czanderna and G.J. Jorgensen; *Presented at Photovoltaics for the 21st Century Seattle, Washington, May 4, 1999*

Both durability & reliability issues: A hypothetical representation

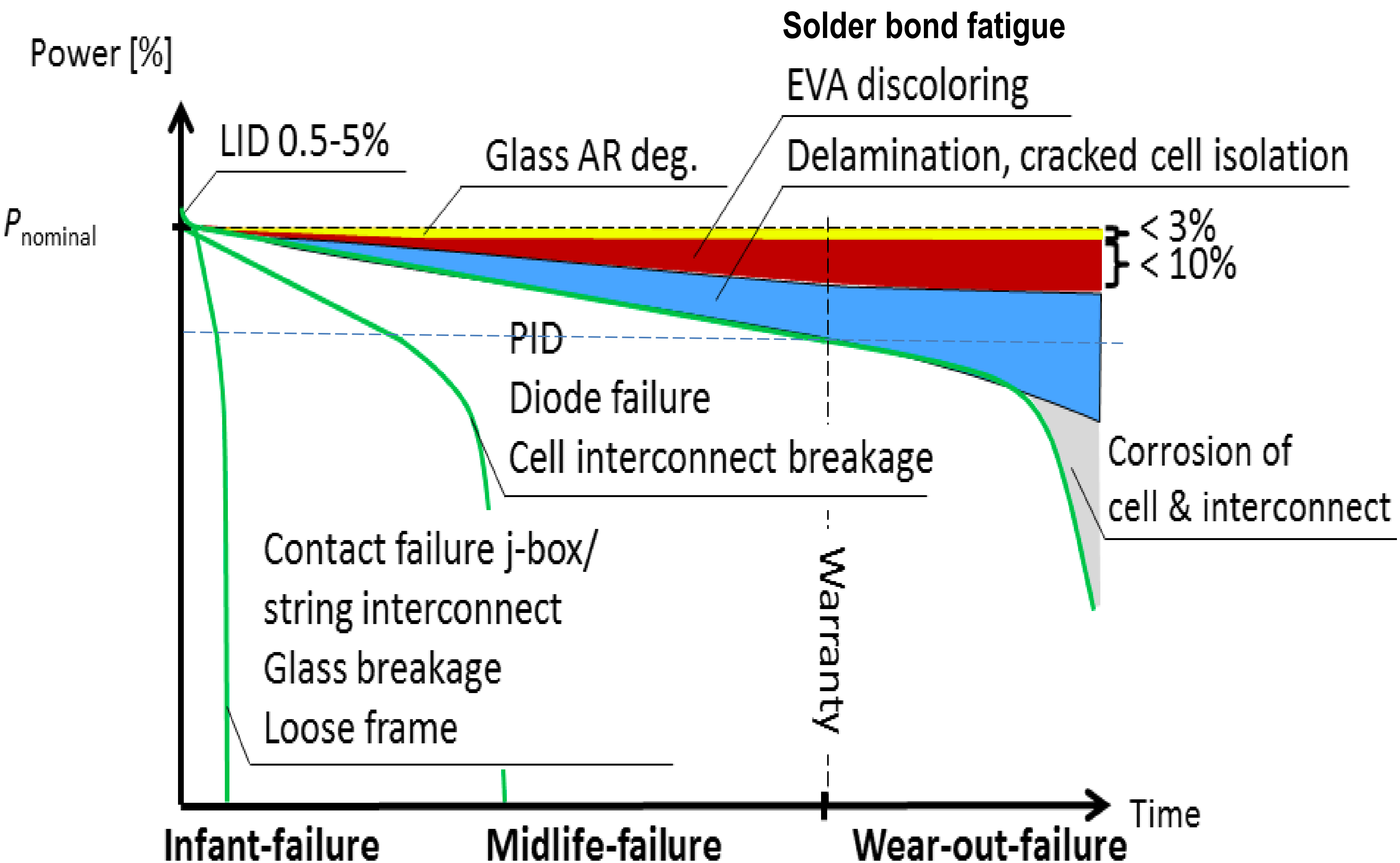


Practical implication of these issues for stakeholders:

- **Higher $/kWh**
- **Not bankable (high risk premium rate and O&M insurance backup!)**

Source: ASU-PRL (Solar ABCs report)

Both durability & reliability issues: A hypothetical representation



Source: IEA-PVPS-2014

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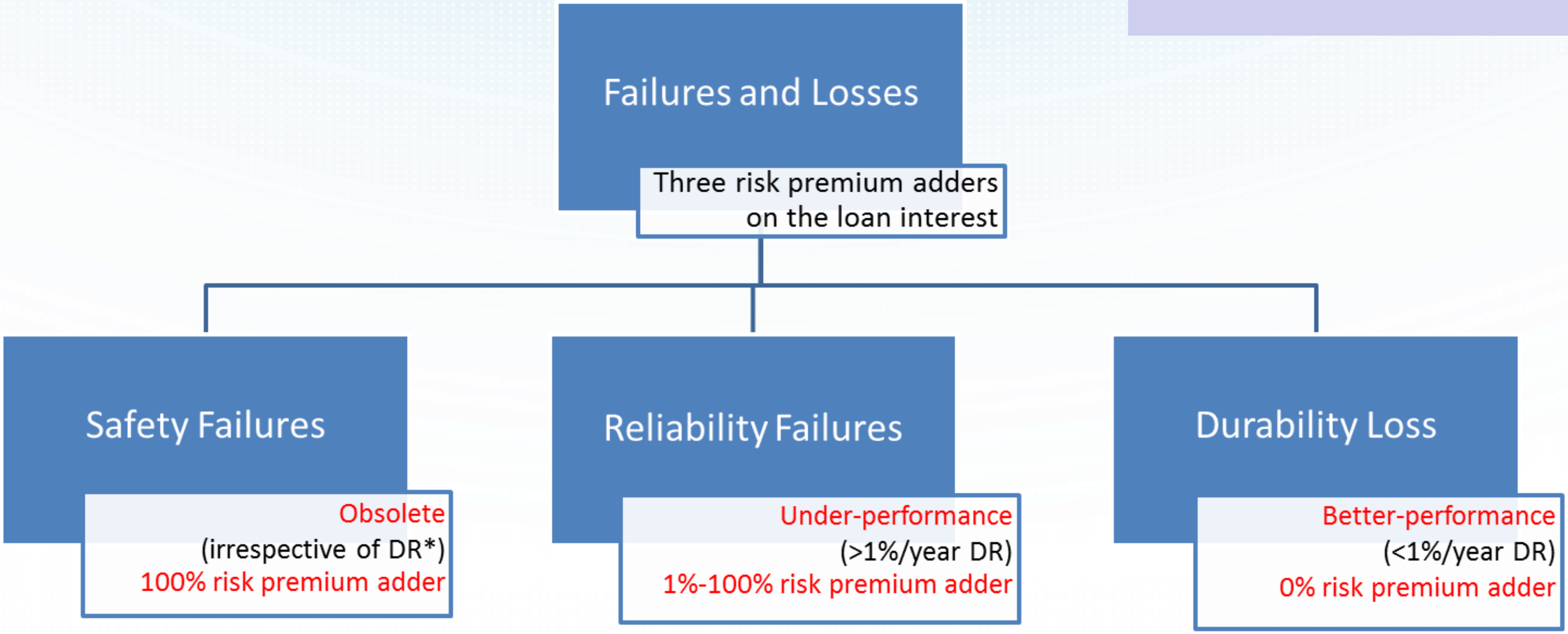
Importance of durability

Goal of project developers:
Securing low interest bank loan with no risk premium adders

Interest Rate
=
Interest Rate @ Zero Risk
+
Risk Premium Rate



*DR = Degradation Rate

Note: The typical 20/20 warranty is assumed in the above example.

Reliability evaluation: Importance to stakeholders

To decrease levelized cost of energy (**$/kWh**) by decreasing **"$/kW"** value and increasing **"h"** value.

Technical Levelized Cost of Energy (T-LCOE) of PV Module

$/kWh = Bankability

Performance → **$/kW**

Safety, Reliability and Durability → **h**

"$/kW" dictated by:

- **Material cost ($): Materials and process cost per unit area**
- **Device Quality (kW): Module efficiency per unit area**

"h" dictated by:

- **Packaging / Design Quality: Safety failures (SF) over time (obsolete)**
- **Manufacturing Quality: Reliability failures (RF) over time (under-performance; >1%/year degradation)**
- **Material Quality: Durability / Degradation loss (DL) over time (better-performance; <1%/year degradation)**

SF = Safety Failure (Qualifies for safety returns); Identified by: Visual inspection, IR and Circuit/diode checker

RF = Reliability Failure (Qualifies for warranty claims); Identified by: I-V

DL = Durability Loss (Does not qualify for warranty claims); Identified by: I-V

Source: ASU-PRL

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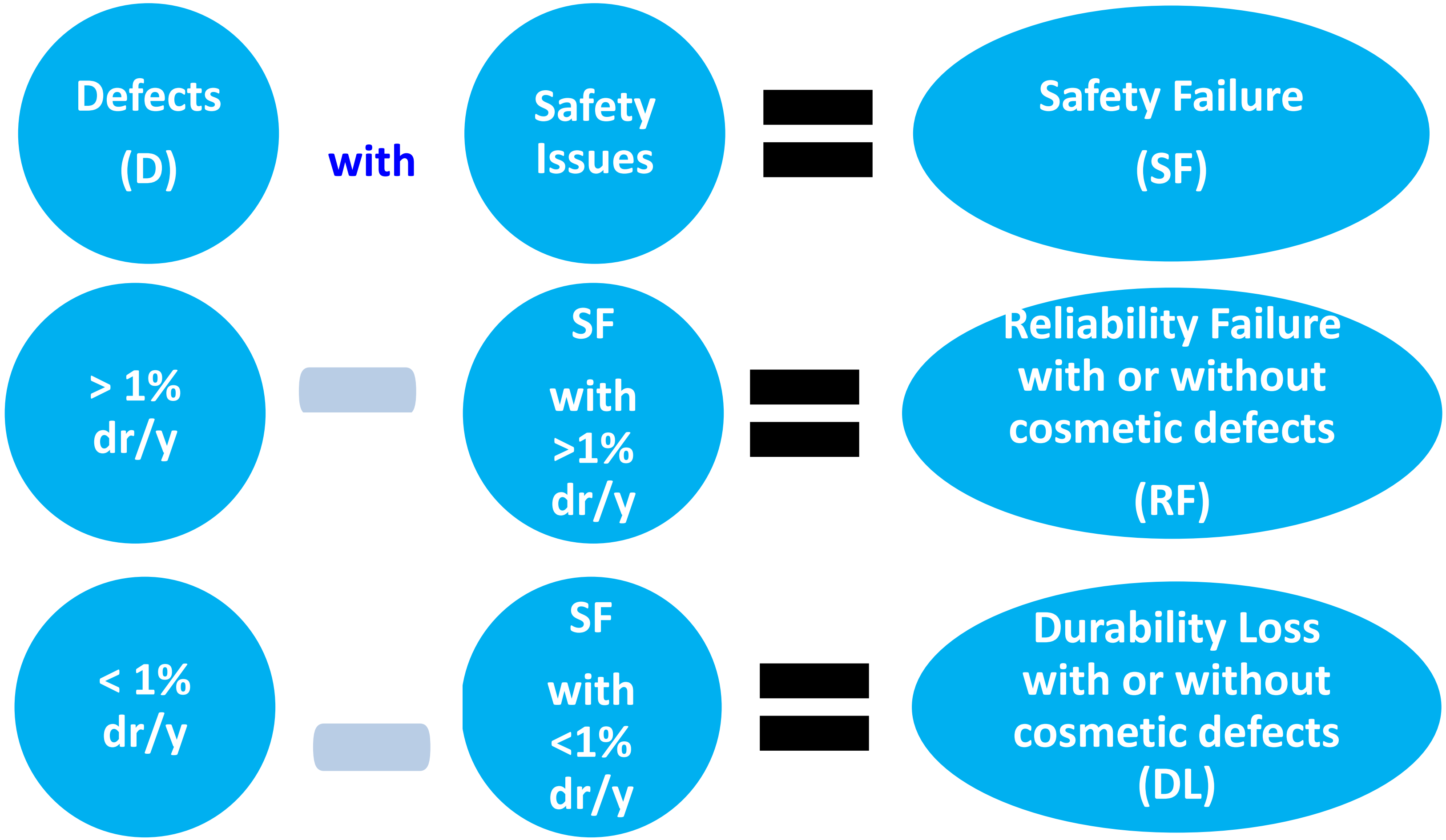
Outdoor durability evaluation

METRIC/NUMERIC Definition of Failures and Degradation

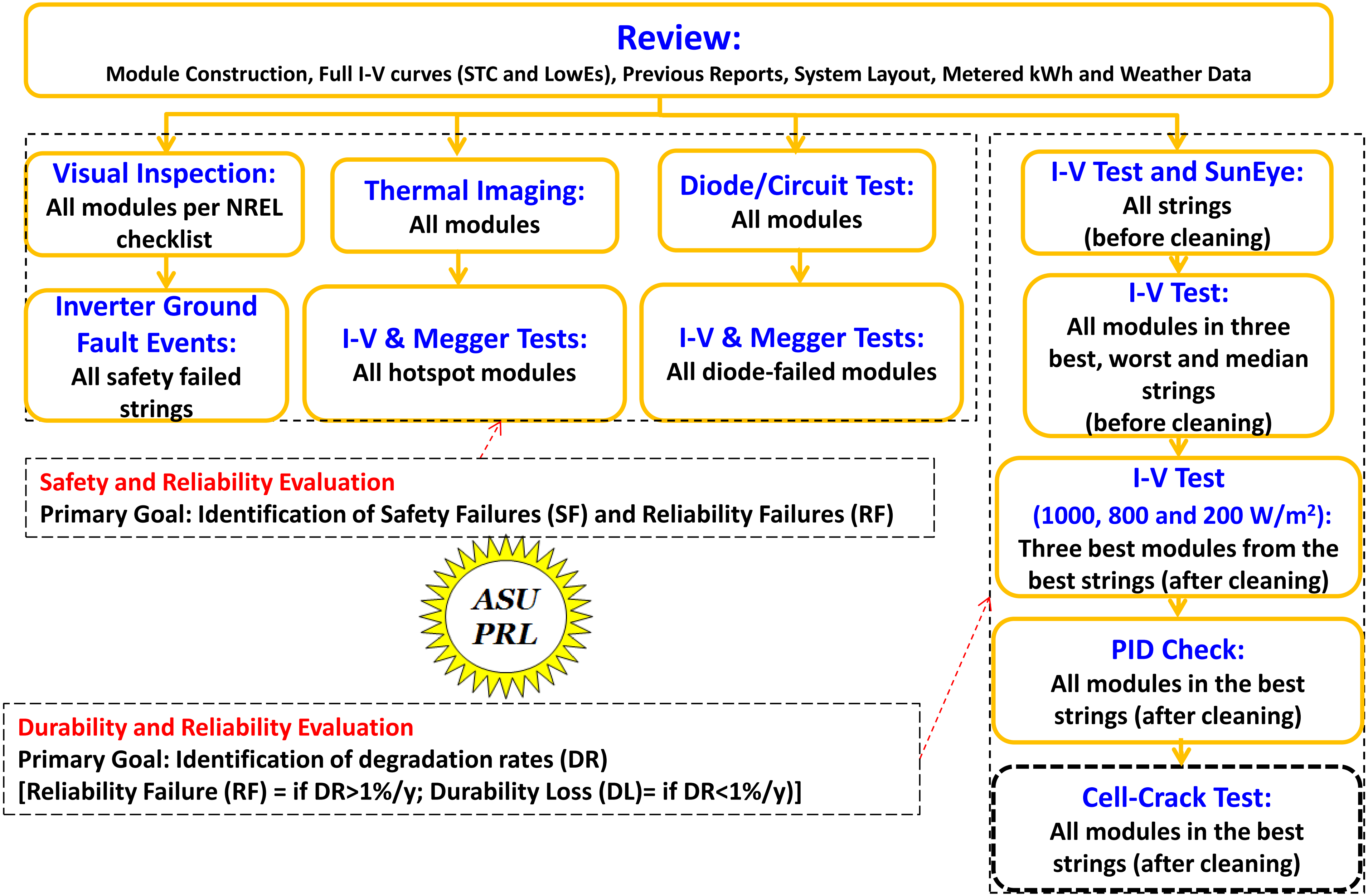


DR = Degradation Rate

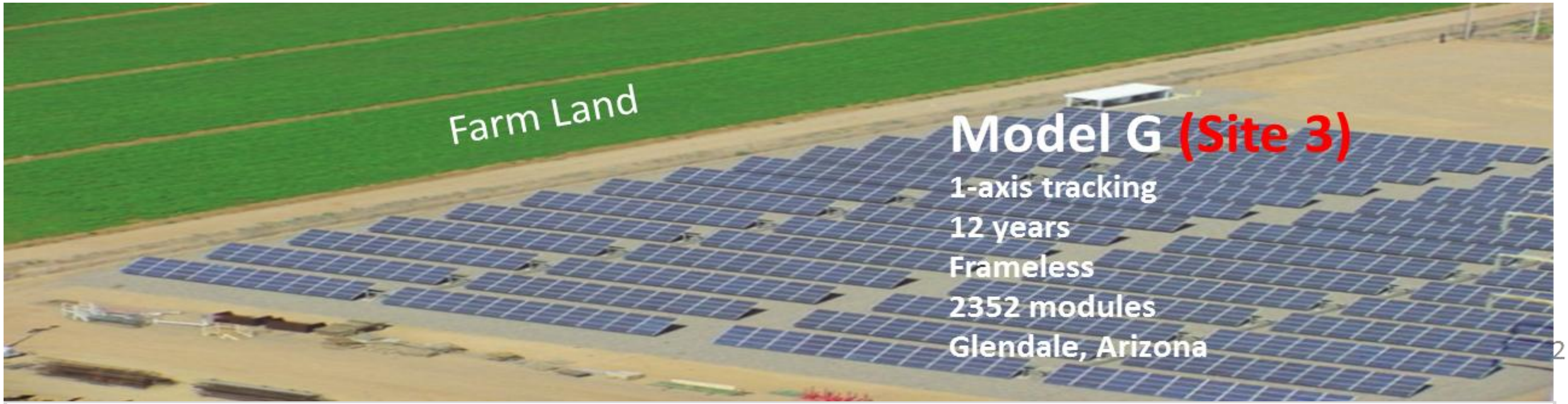
SF = Safety Failure (100% risk; Qualifies for safety returns;)
RF = Reliability Failure (1-100% risk proportional to DR; Qualifies for warranty claims)
DL = Durability Loss (0% risk; Does not qualify for warranty claims)

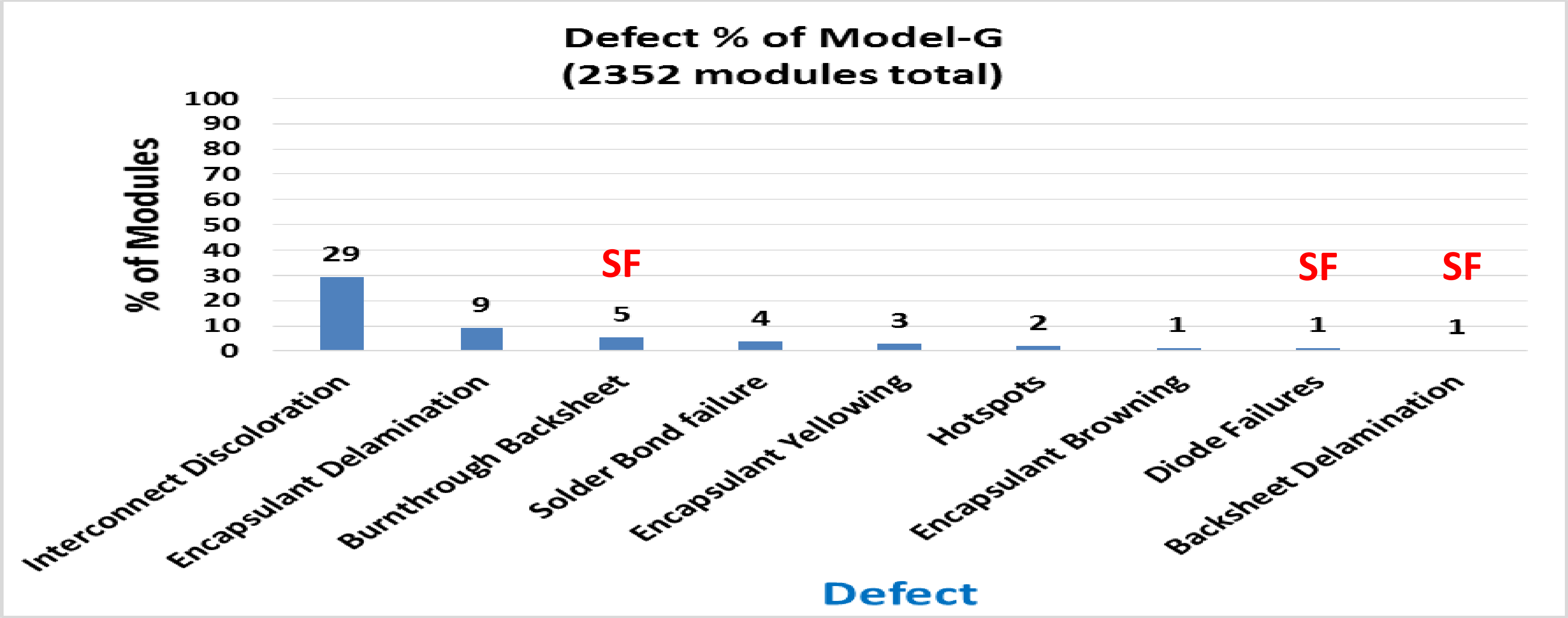
Field Evaluation of PV Modules:

Application of ASU-PRL's Definitions on Field Failures and Degradation Determinations



Defects (mono-Si; glass/polymer)





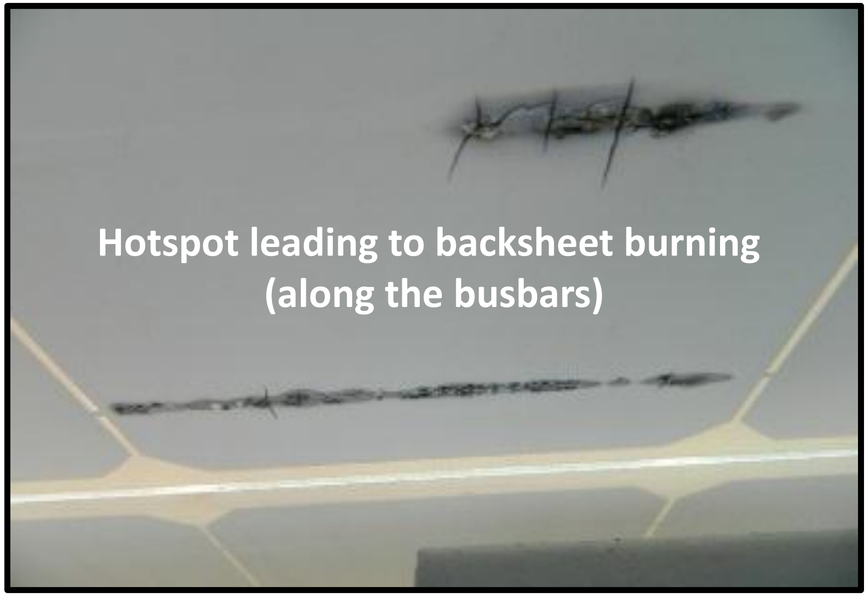
SF = Safety Failure; **RF** = Reliability Failure; **DL** = Degradation Loss

Defects with safety issues are identified on the plot.

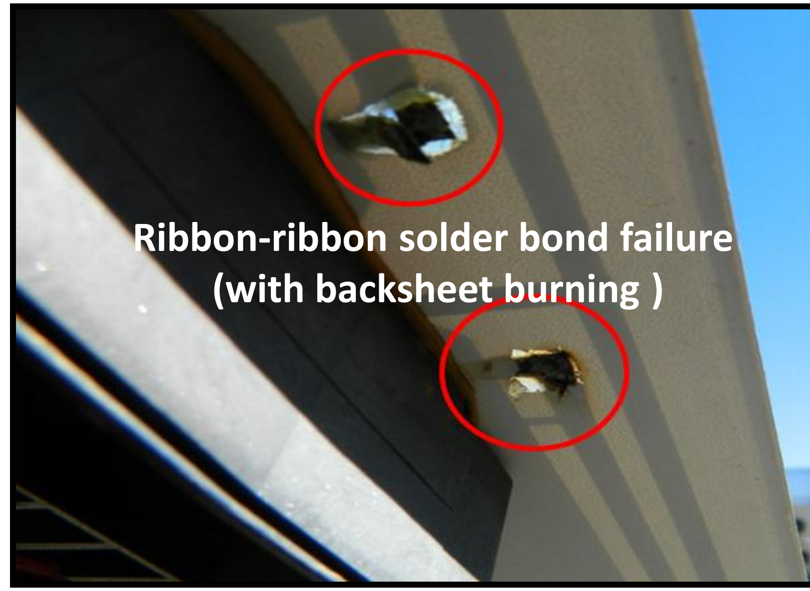
Other defects shown on the plot are classified as either RF or DL depending on degradation rates

Examples of Safety Failures

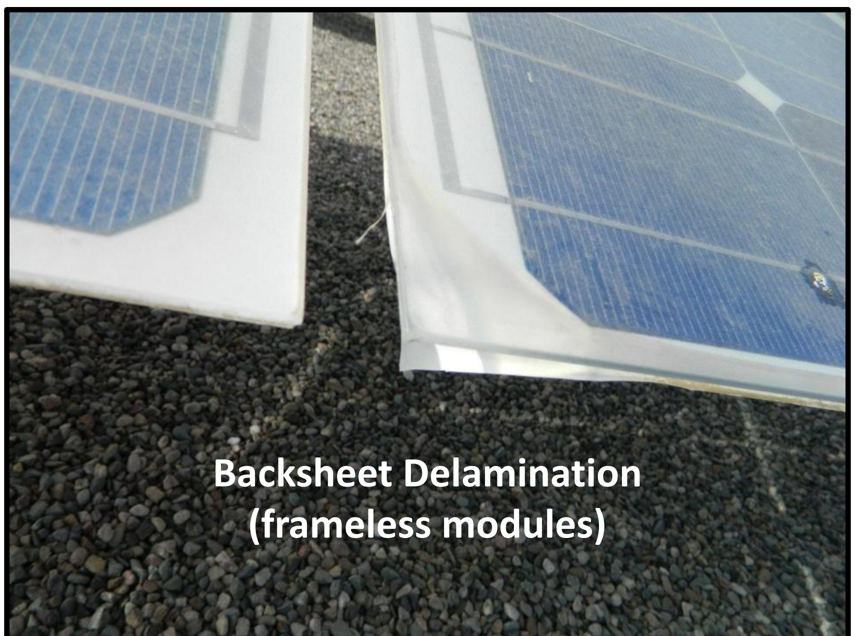
12 Years – 1-axis Tracker



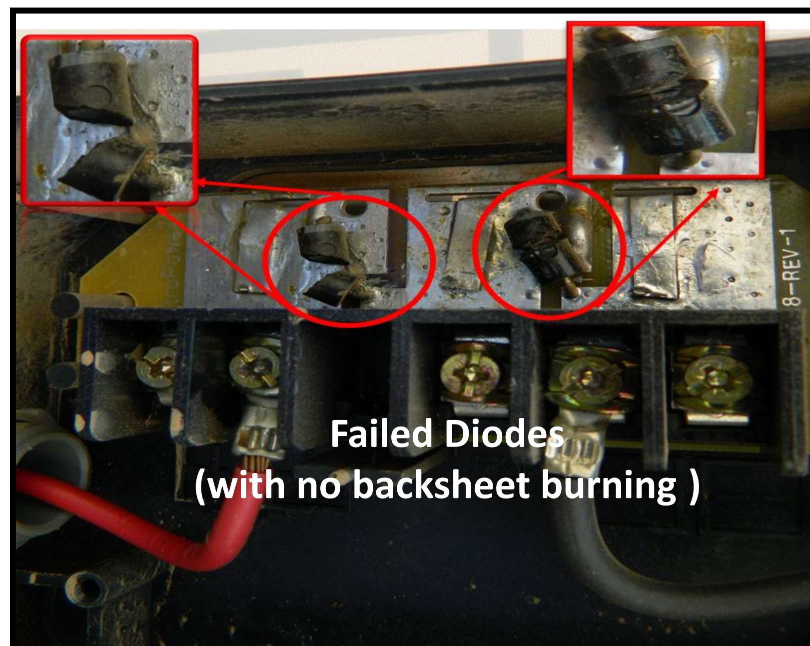
Hotspot leading to backsheet burning
(along the busbars)



Ribbon-ribbon solder bond failure
(with backsheet burning)



Backsheet Delamination
(frameless modules)

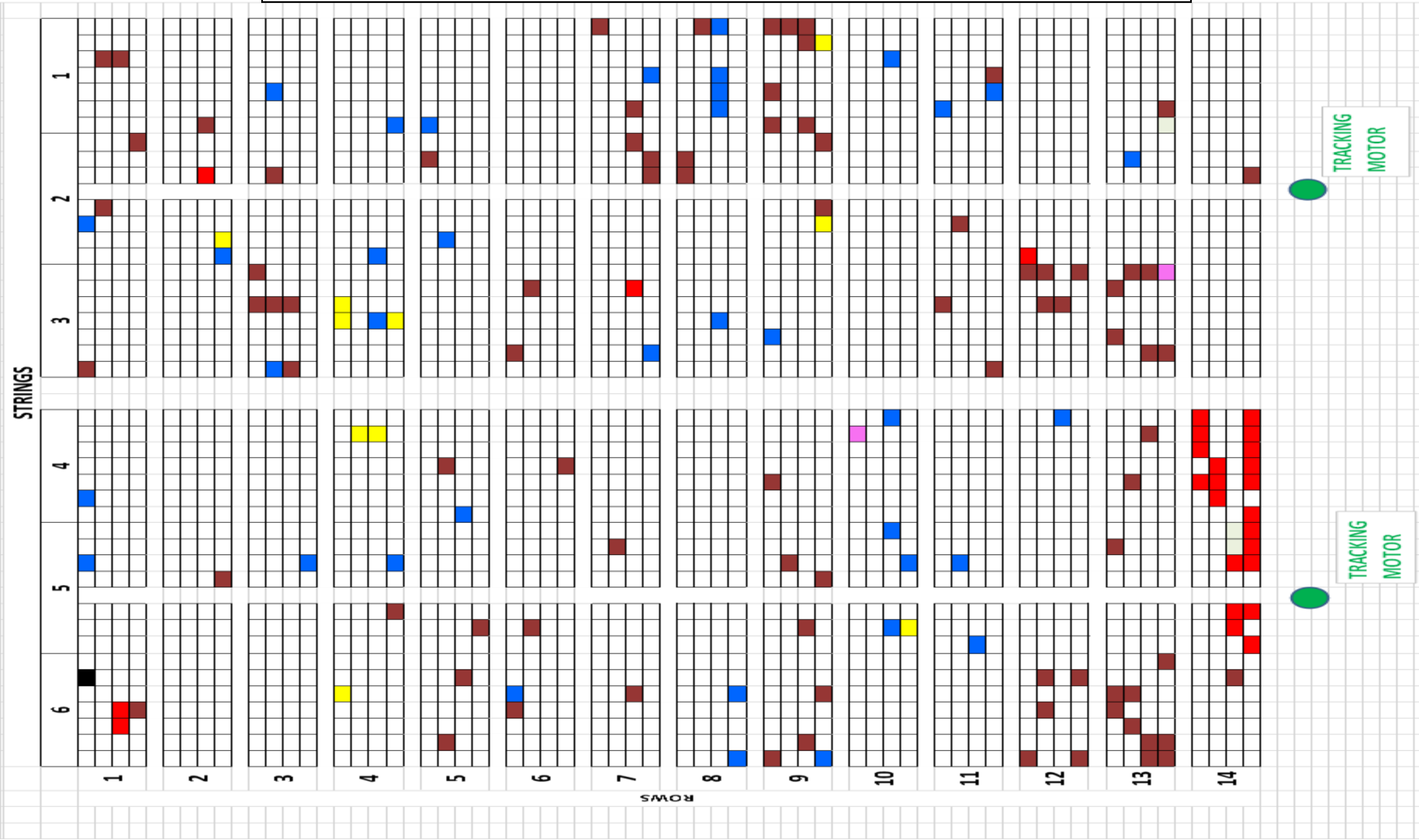


Failed Diodes
(with no backsheet burning)

Mapping of Safety Failures (*Model G – Site 3*)

Framed - 12 Years – 1-axis Tracker

Safety failure rate at the plant level = 162/2352 = 7%

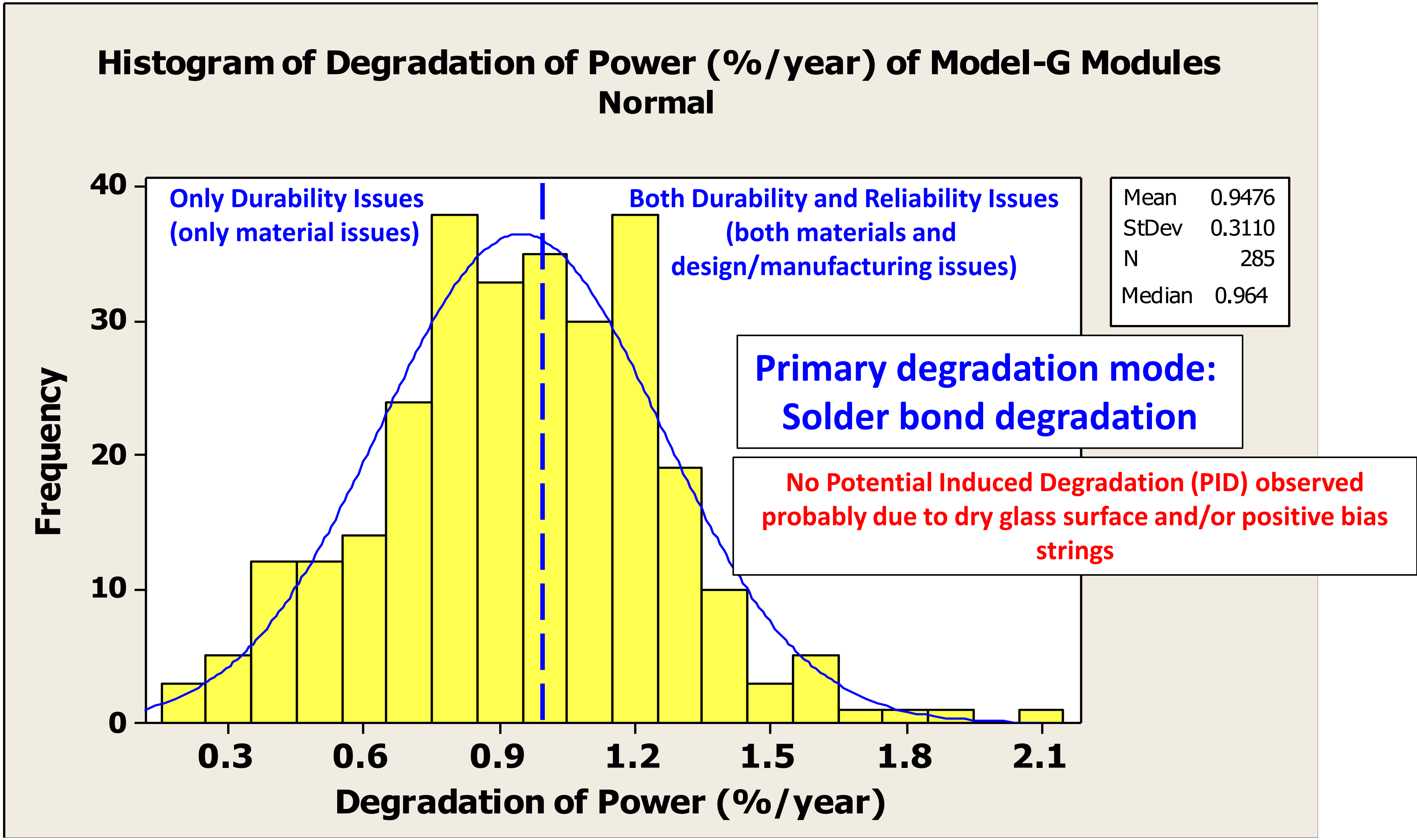


- Hotspot issues leading to backsheet burn (37/2352)
- Ribbon-ribbon solder bond failure with backsheet burn (86/2352)
- Failed diode wih no backsheetburn (26/2352)
- Hotspot issues with backsheet burn + Ribbon-ribbon solder bond with backsheet burn (1/2352)
- Backsheet Delamination (10/2352)
- Backsheet Delamination + Ribbon-ribbon solder bond failure (2/2352)

Primary failure mode:
Ribbon-ribbon solder bond failure with backskin burning

Distribution of Reliability Failures and Degradation Losses (*Model G – Site 3*)

12 Years – 1-axis Tracker

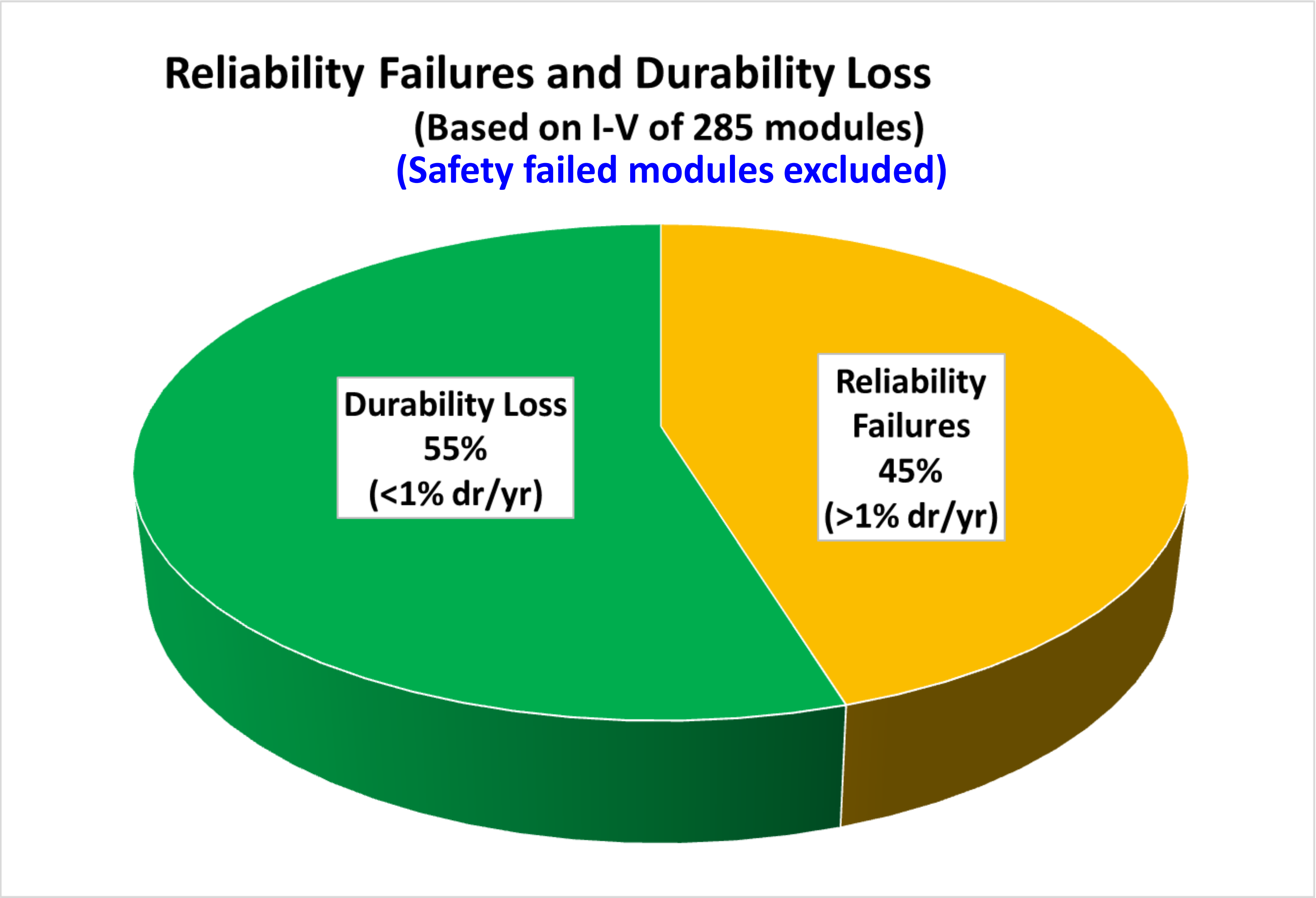


Total number of modules = 285 (safety failed modules excluded)

Average degradation = 0.95%/year

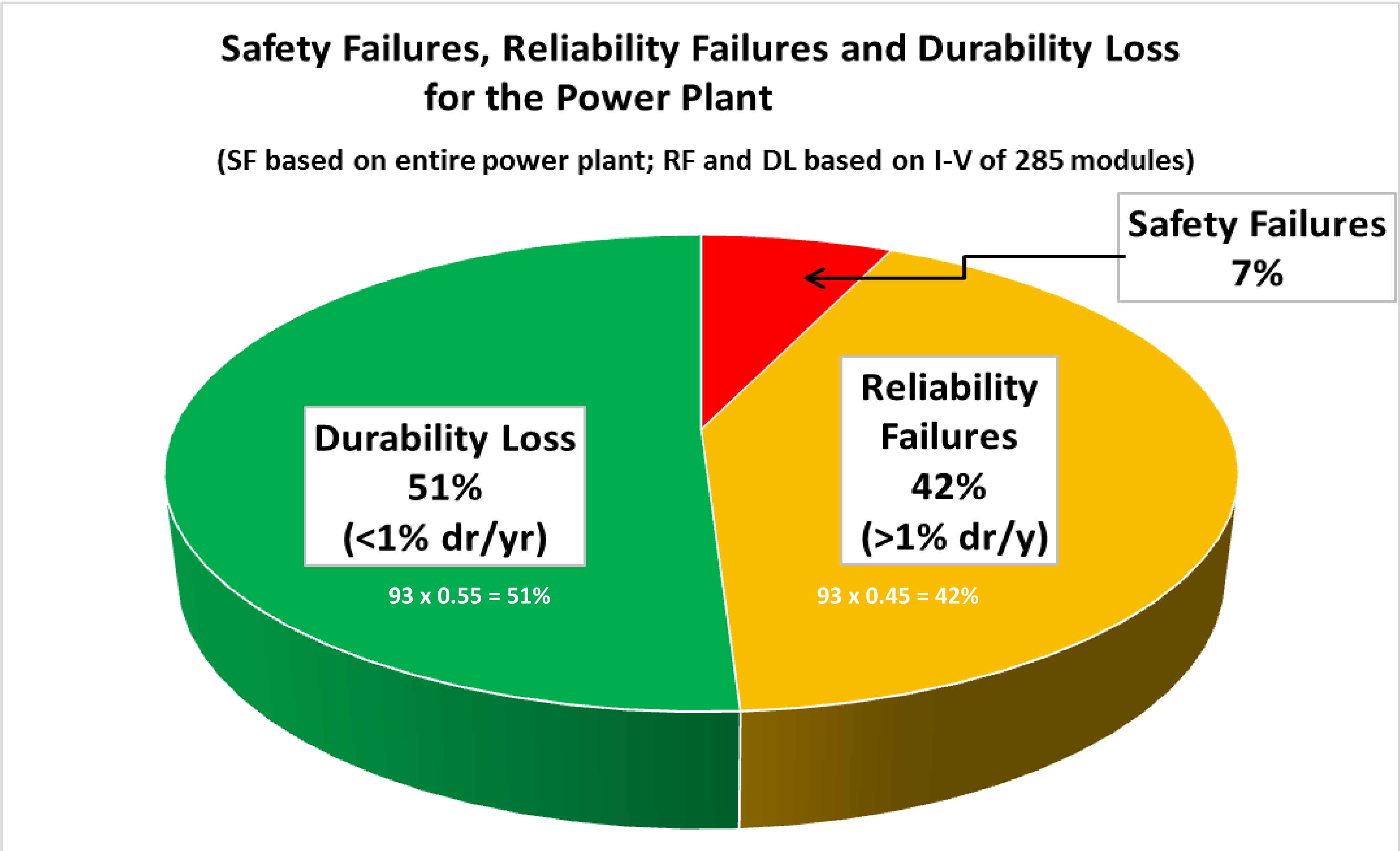
Distribution of Reliability Failures and Degradation Losses (*Model G – Site 3*)

12 Years – 1-axis Tracker



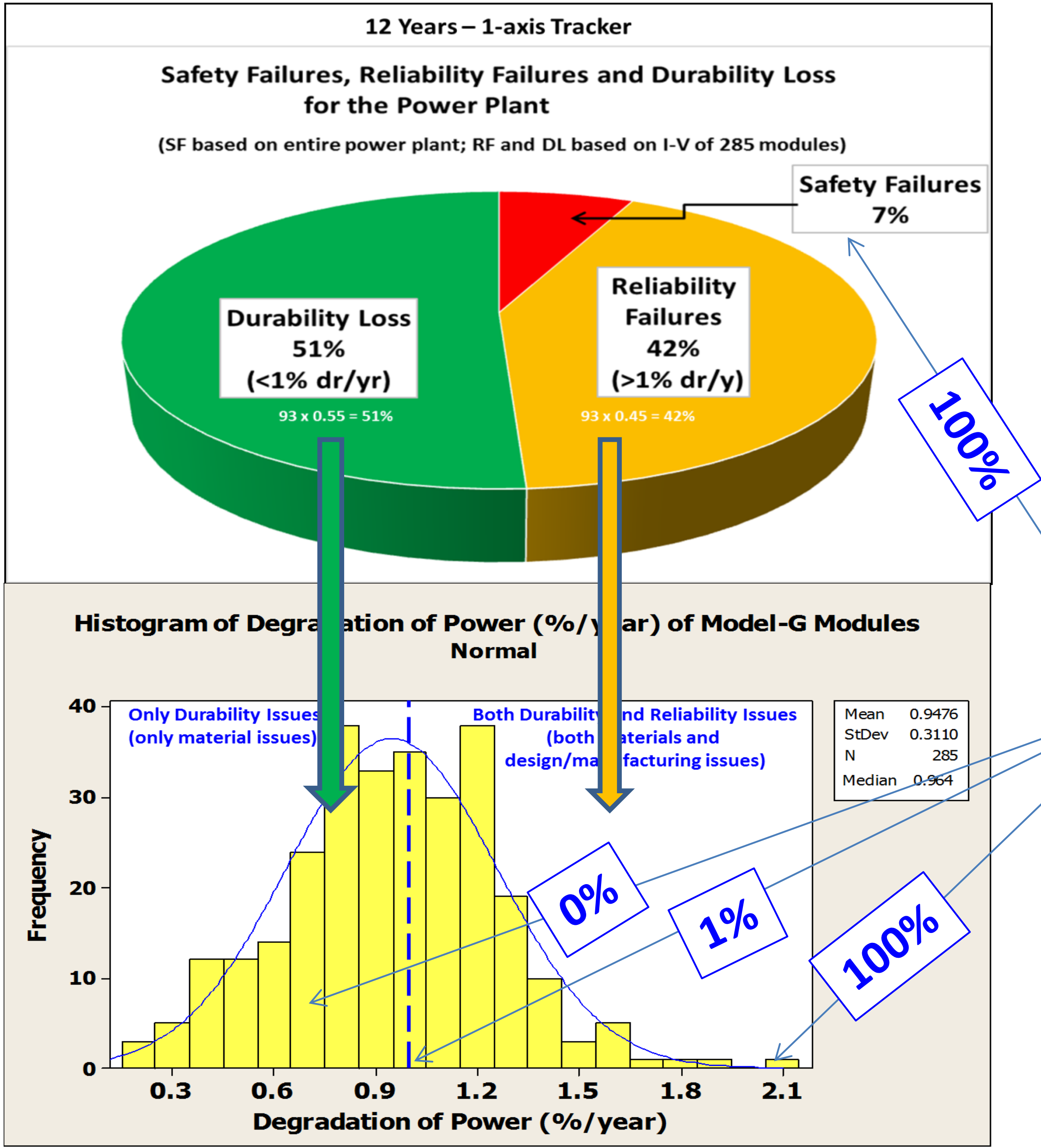
Distribution of Safety Failures, Reliability Failures and Degradation Losses (*Model G – Site 3*)

12 Years – 1-axis Tracker (combination of previous two slides)



Linking Field Evaluation Data with Premium Risk Rate Calculation

A Conceptual Representation



Interest Rate

=

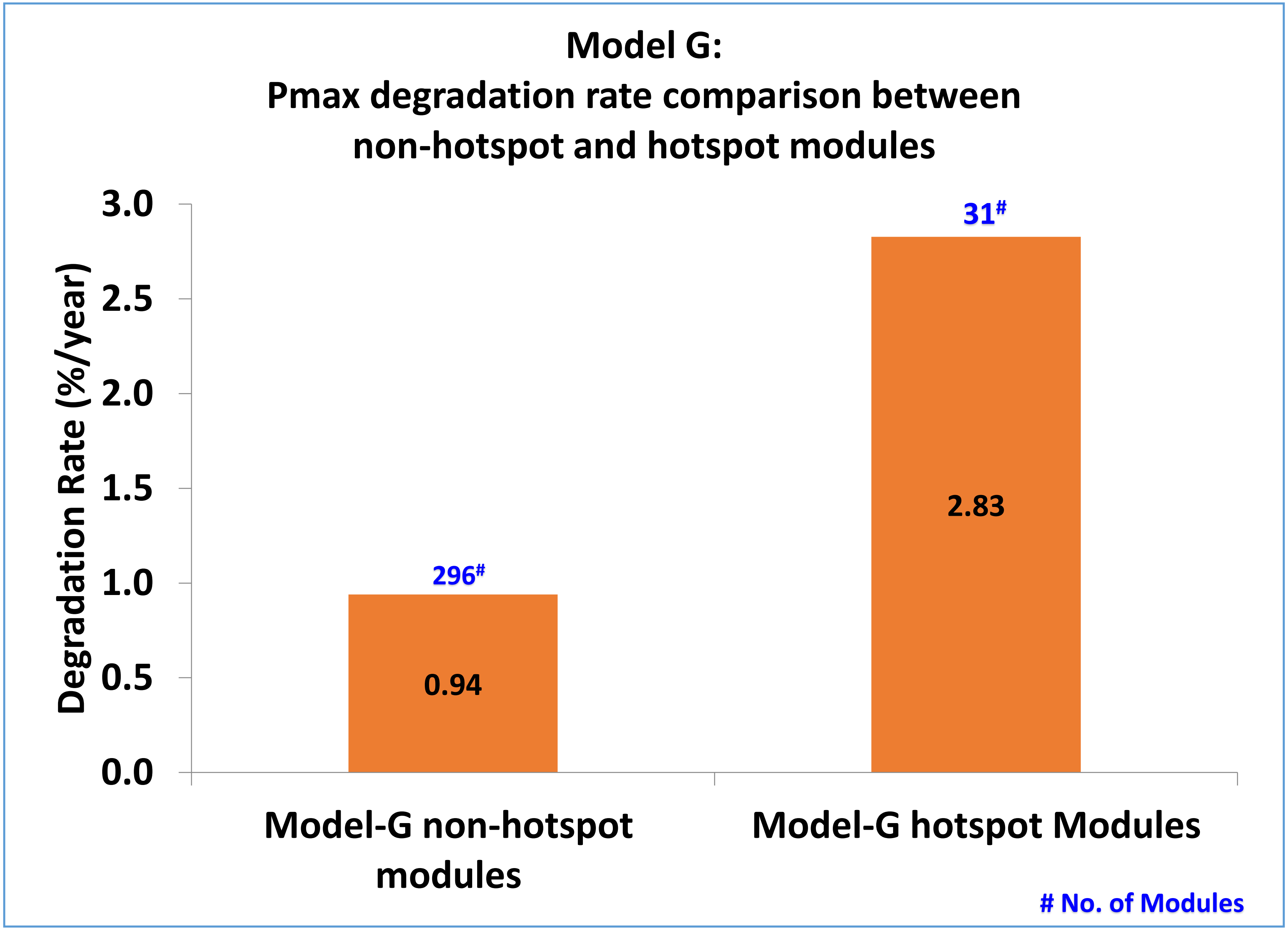
Interest Rate @ Zero Risk

+

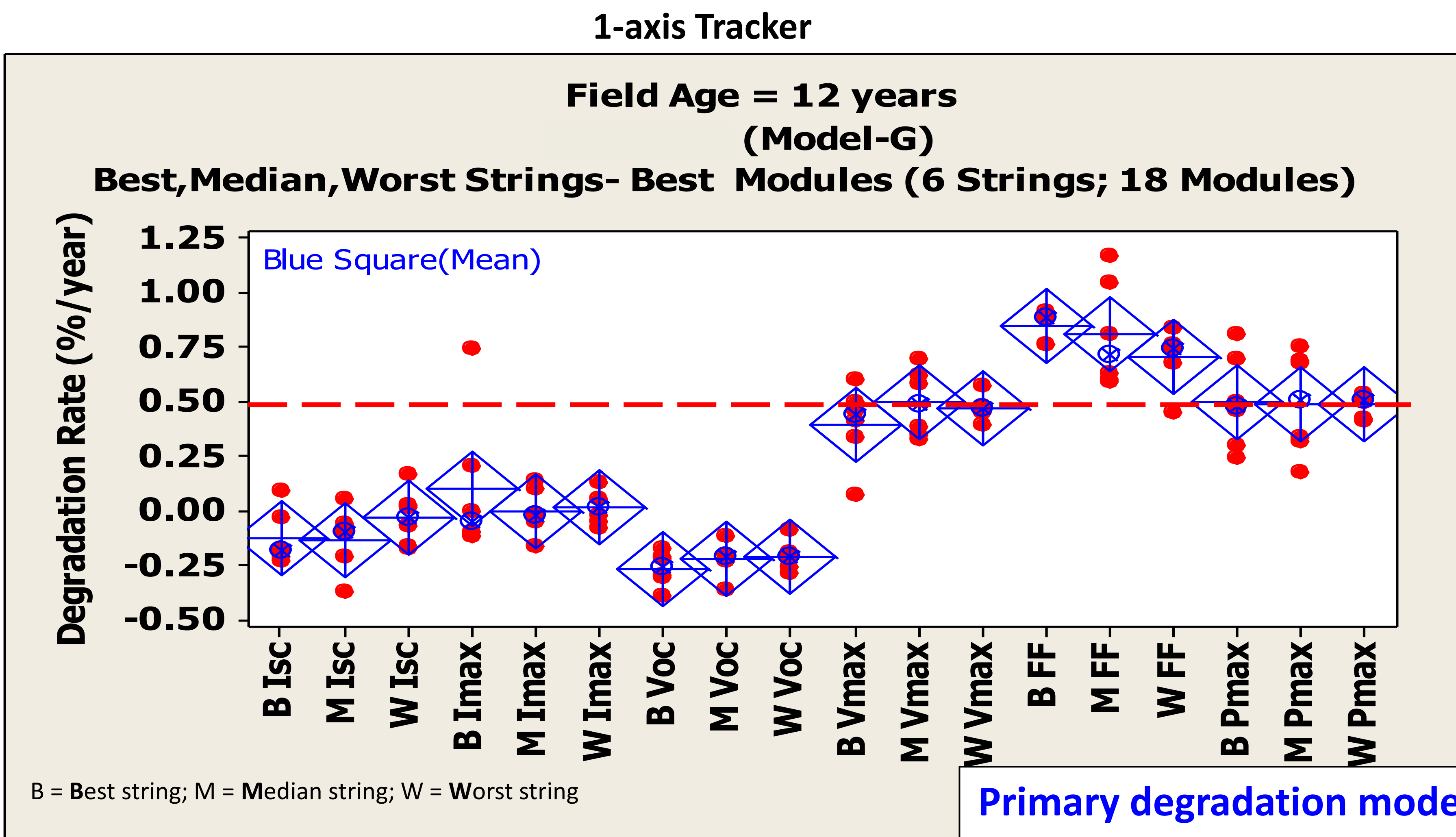
Risk Premium Rate

Risk Premium Rate Calculation

Hotspot modules degrade at higher rates (>3 times) (*Model G – Site 3*)



Best Modules Experienced Only Durability Issues (*Model G – Site 3*)



Primary degradation mode: Solder bond degradation

Pmax loss → FF loss → Rs increase

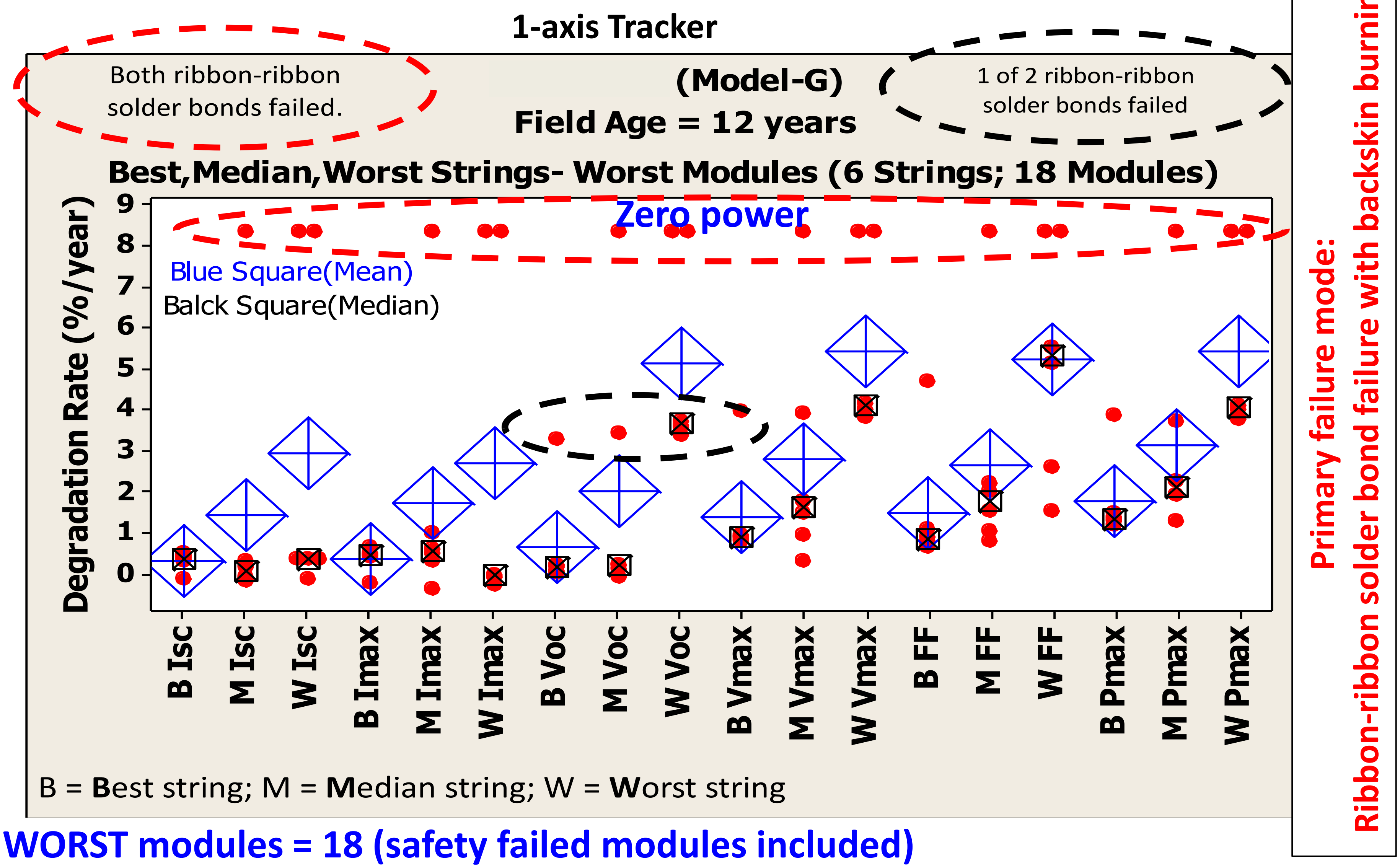
BEST modules = 18 (safety failed modules excluded if any)

Mean degradation = 0.5%/year

Median degradation = 0.5%/year

} ***Due to only intrinsic (materials) issues contributing to real wear out mechanisms***

Worst Modules Experienced Both Reliability and Durability Issues (*Model G – Site 3*)



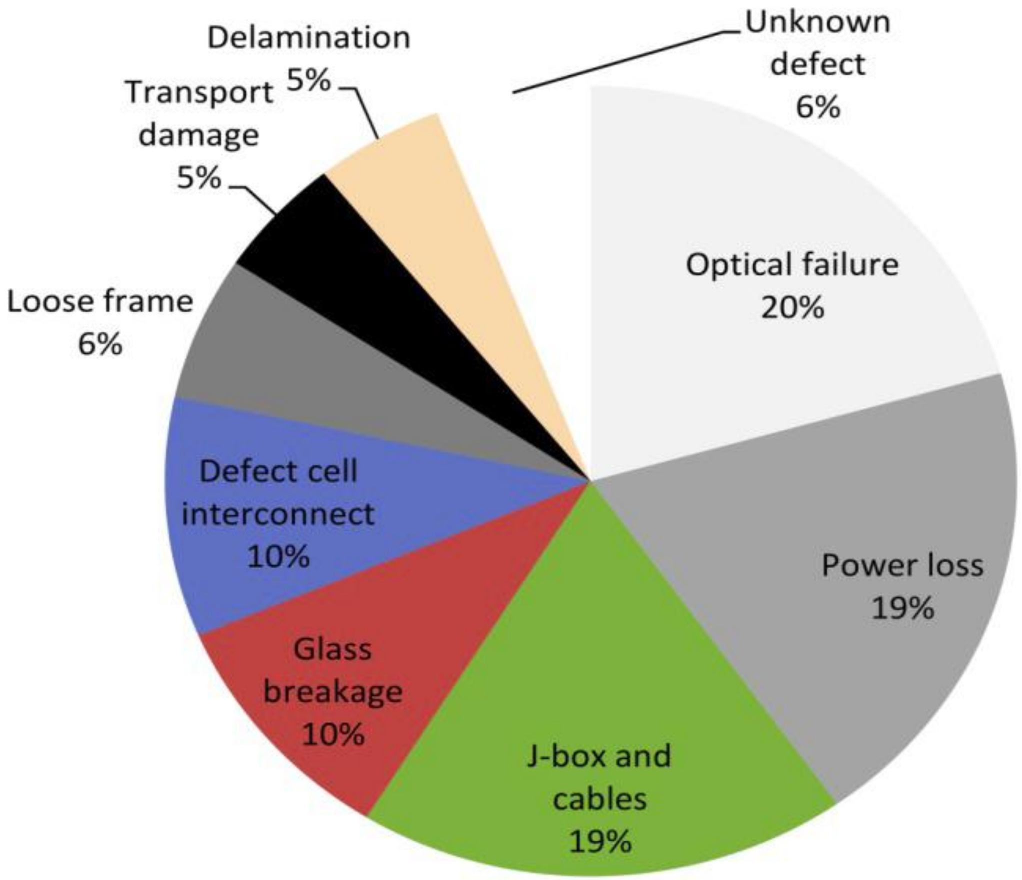
WORST modules = 18 (safety failed modules included)

Mean degradation = 1.8-5.6%/year
Median degradation = 1.4-4%/year

Due to both intrinsic (materials) and extrinsic (design/manufacturing) issues

FAILURE & DEGRADATION MODES WITHOUT RISK PRIORITIZATION

Germany (cold-dry climate); ~ 2 Years & ~2 million modules

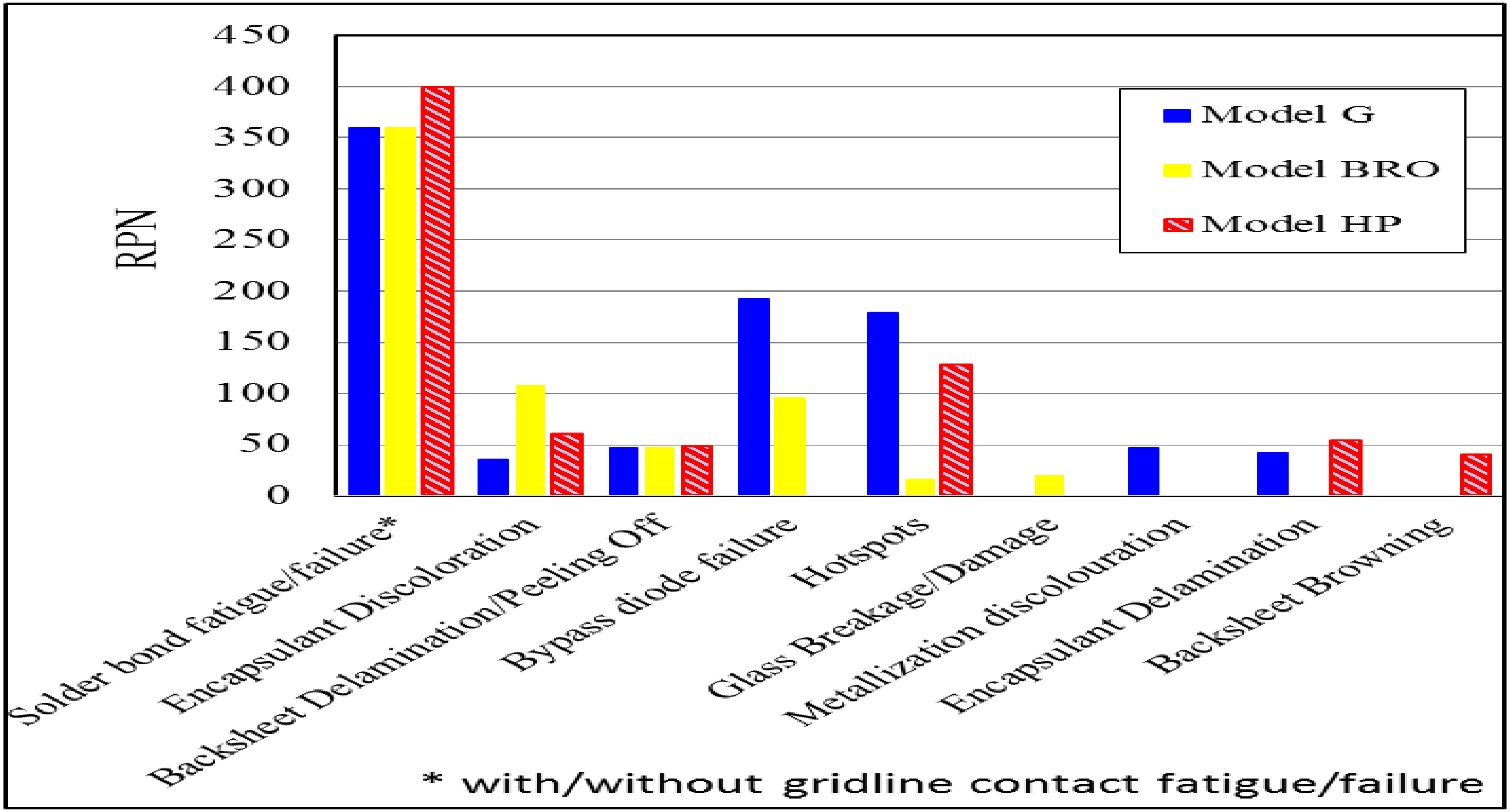


Not all defects are failures:
Cosmetic defects should not be considered;
Modes shall be risk prioritized for each climatic condition and each module construction type

Source: IEA-PVPS-2014

FAILURE & DEGRADATION MODES WITH RISK PRIORITIZATION

Arizona (hot-dry climate); 6-16 Years & ~6000 modules



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Modes shall be risk prioritized for each climatic condition and each module construction type

Souce: ASU-PRL

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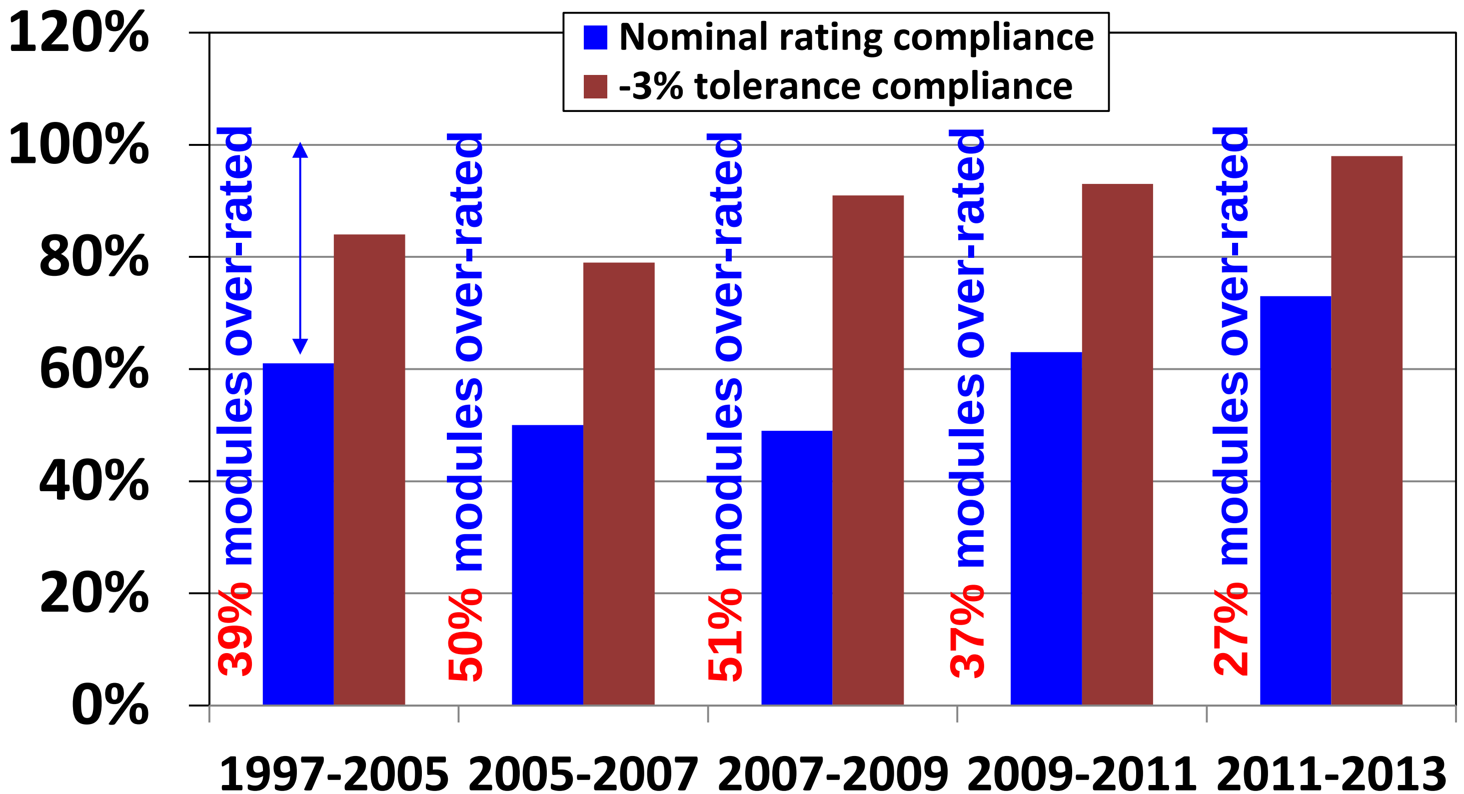
Indoor durability evaluation

Degradation rate calculation may be influenced by nameplate rating practice which in turn is influenced by demand & supply of the market



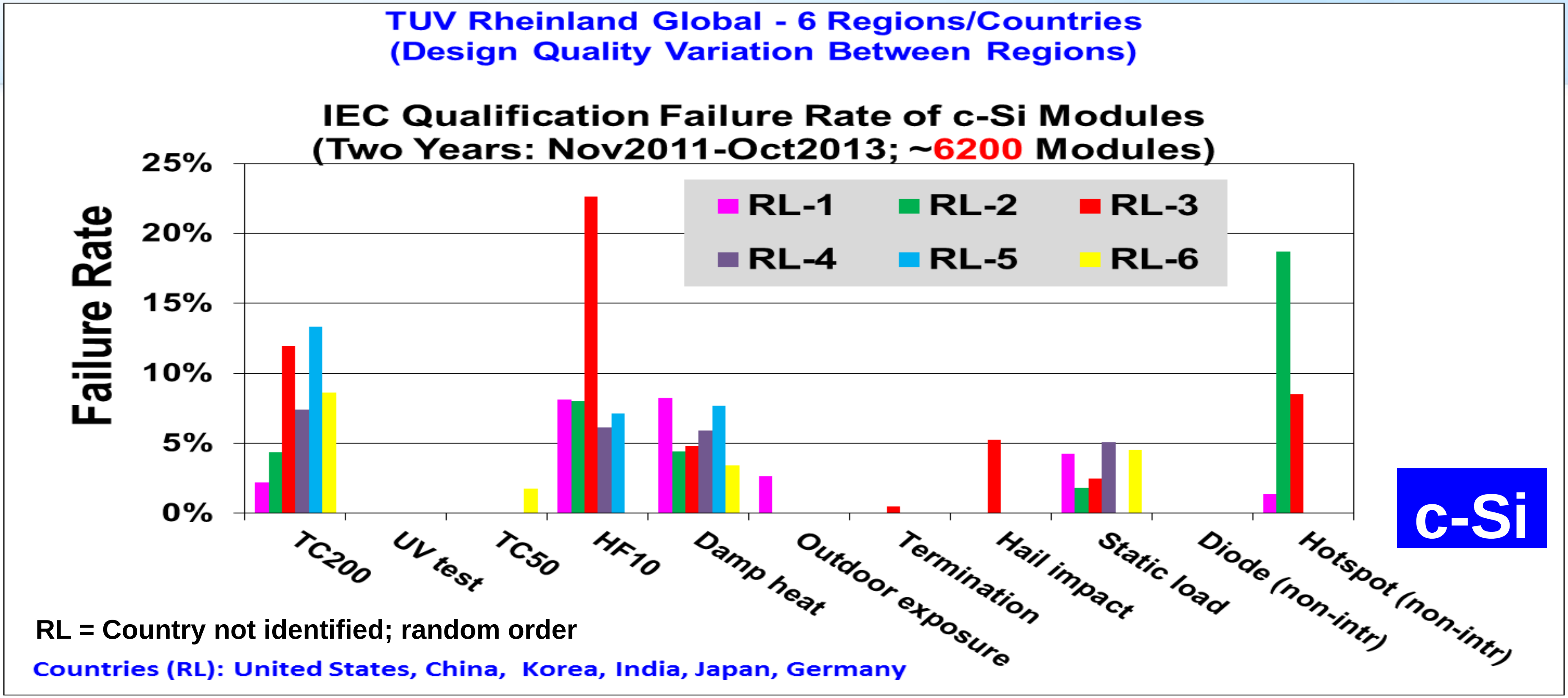
	1997-2005	2005-2007	2007-2009	2009-2011	2011-2013
# Modules	389	278	304	478	825

Under-rated modules will show POSITIVE degradation rate

Over-rated modules will show OVERLY NEGATIVE degradation rate

- Cross check the degradation rate with kWh based degradation rate using Performance Index (PI) method

Degradation rate may depend on the country of production



Stark design quality variation between the regions has been observed.

- HF10 test: Region/country 3 (RL-3) has the highest and abnormal failure rate
  - ➢ Potential reasons: Polymeric material and/or interface issue
- Hotspot test: Region/country 2 (RL-2) has the highest and abnormal failure rate
  - ➢ Potential reasons: Cell quality and/or tabbing issue
- TC200 test: Almost all the regions/countries suffer
  - ➢ Potential reasons: Metallic material and/or interface issue

Degradation rate can be decreased through beyond-Qualification tests such as Qualification Plus, Comparative and Lifetime tests

THREE TYPES OF ACCELERATED TESTS

	Qualification	Comparative	Lifetime
Purpose	Minimum design requirement	Comparison of products	Substantiation of warranty
Quantification	Pass/fail	Relative	Absolute
Climate or Application (Mounting)	Not differentiated	Differentiated	Differentiated

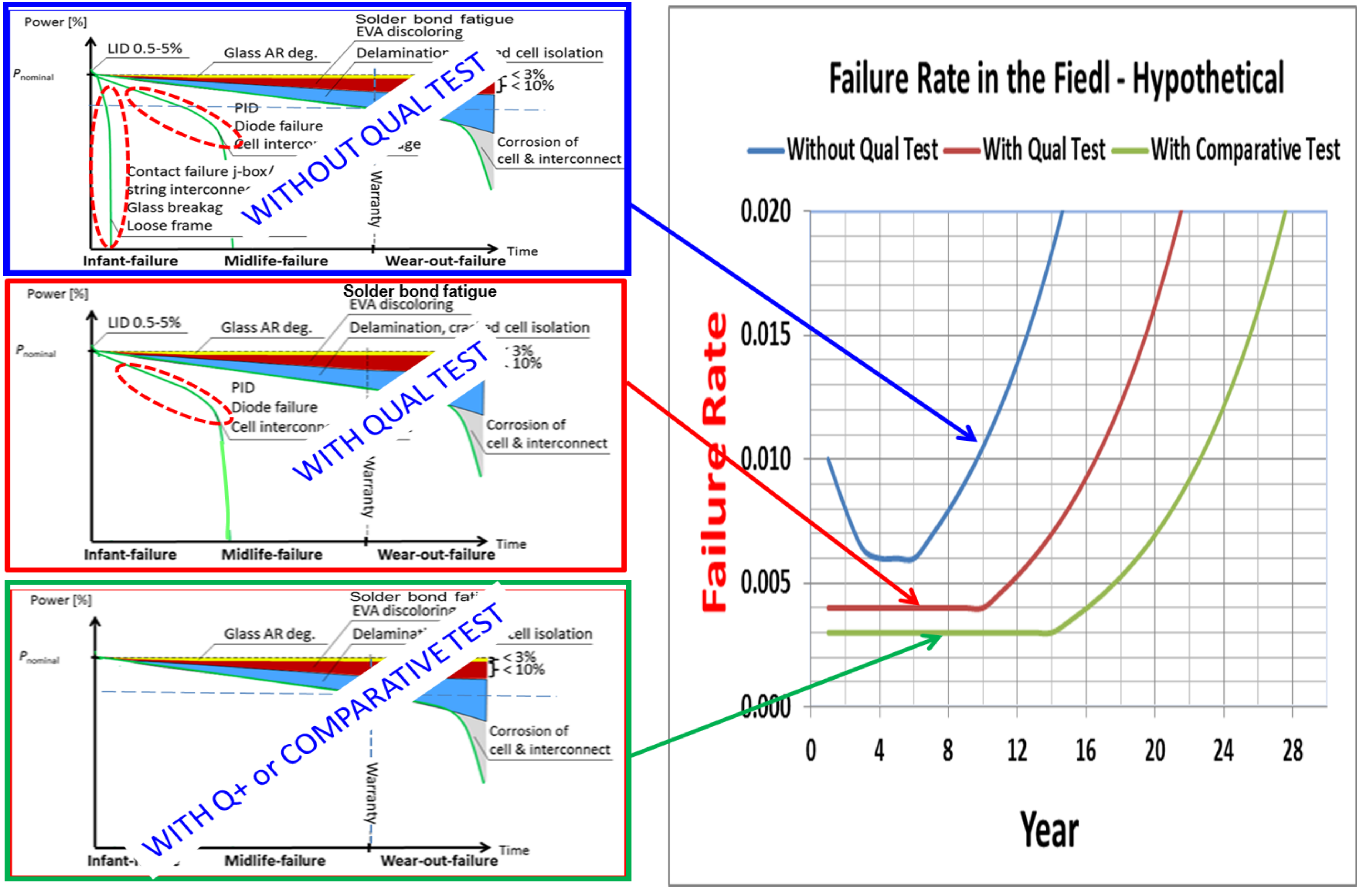
Existing

New test

Qualification PLUS

Source:
Kurtz et al, NREL, IEEE PVSC 2013; TamizhMani et al, ASU, SolarABCs report, 2013

Degradation rate can be decreased through beyond-Qualification tests such as Qualification Plus, Comparative and Lifetime tests



Degradation rate can be decreased through beyond-Qualification tests such as Qualification PLUS

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

ANSI / TUV-R Standard

Photovoltaic Module Qualification Plus Testing

Sarah Kurtz, John Wohlgemuth, Michael Kempe, Nick Bosco, Peter Hacke, Dirk Jordan, David C. Miller, and Timothy J. Silverman
National Renewable Energy Laboratory

Nancy Phillips
3M

Thomas Earnest
DuPont

Ralph Romero
Black & Veatch

December 2013

http://www.nrel.gov/docs/fy14osti/60950.pdf (available for free downloading)

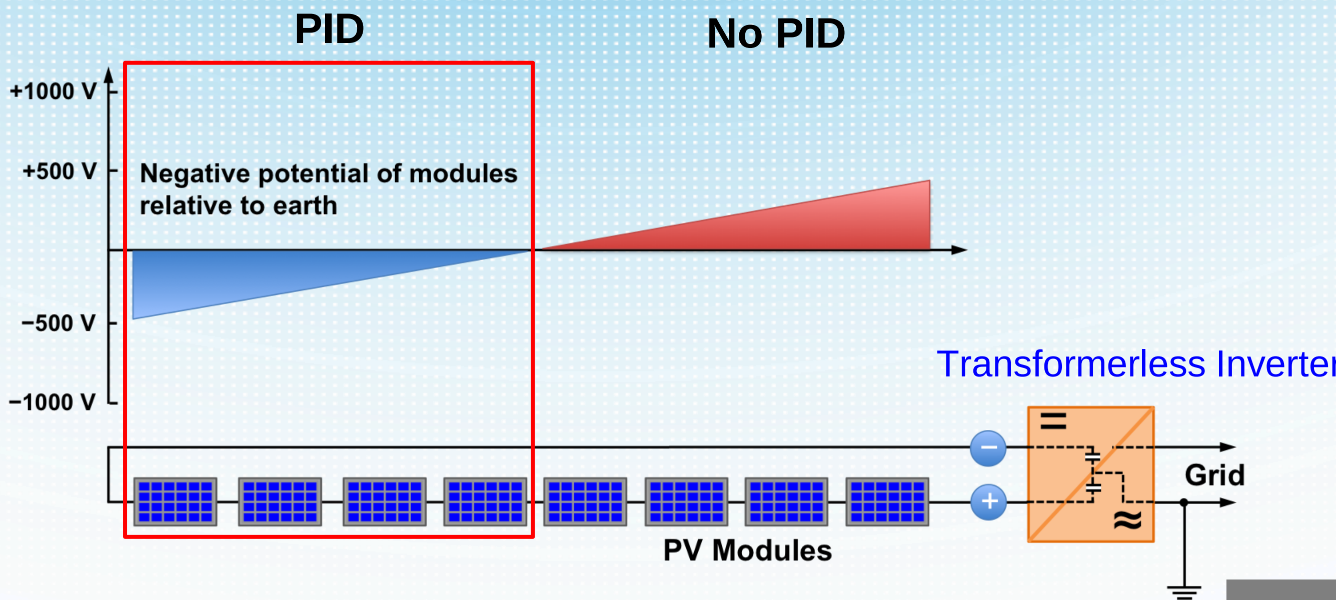
Qualification PLUS Testing Comparison with Qualification Testing

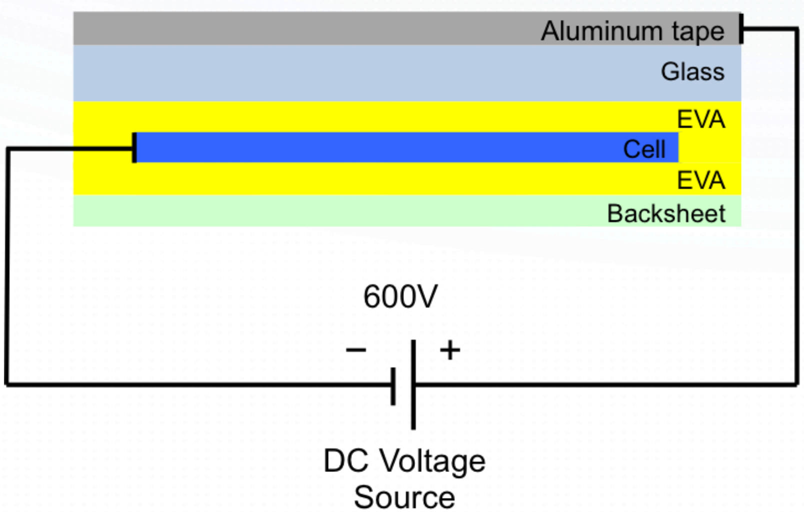
Parameter	Qualification	Qualification PLUS
Module Testing		
Duration	< 3 months	< 3 months
Sample size for each sequence	2	**5**
Thermal cycling test	200 cycles	**500 cycles**
Dynamic load test before the humidity freeze sequence tests	None	**1000 cycles of 1000Pa**
Potential induced degradation (PID)*	Not required	**60°C/85%RH for 96 hours**
Hot spot	Test method not adequate	**Use ASTM E2481-06 method**
Component Testing		
Duration	Not required	**< 6 months**
Sample size for each sequence	None	3-12
UV exposure test for encapsulants, backsheets, connectors, and junction boxes	15 kWh/m^2 @ 60^{o}C and humidity not controlled	224-320 kWh/m^2 @ 50-70^{o}C and humidity controlled
Bypass diode test	1 hour	96 hours
Manufacturing Quality		
Quality Management System (QMS)	Not required	**Addition of PV-specific requirements to ISO9001**

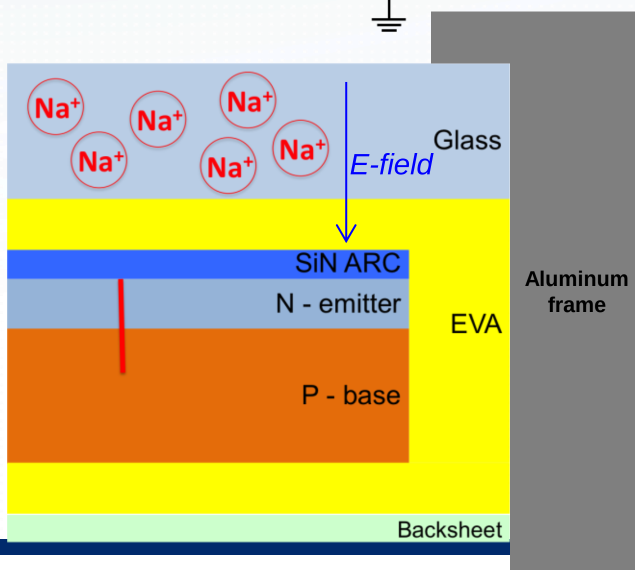
* Discussed further

Source: NREL, Photovoltaic Module Qualification Plus Testing, Kurtz et al, Dec. 2013
http://www.nrel.gov/docs/fy14osti/60950.pdf (available for free downloading)

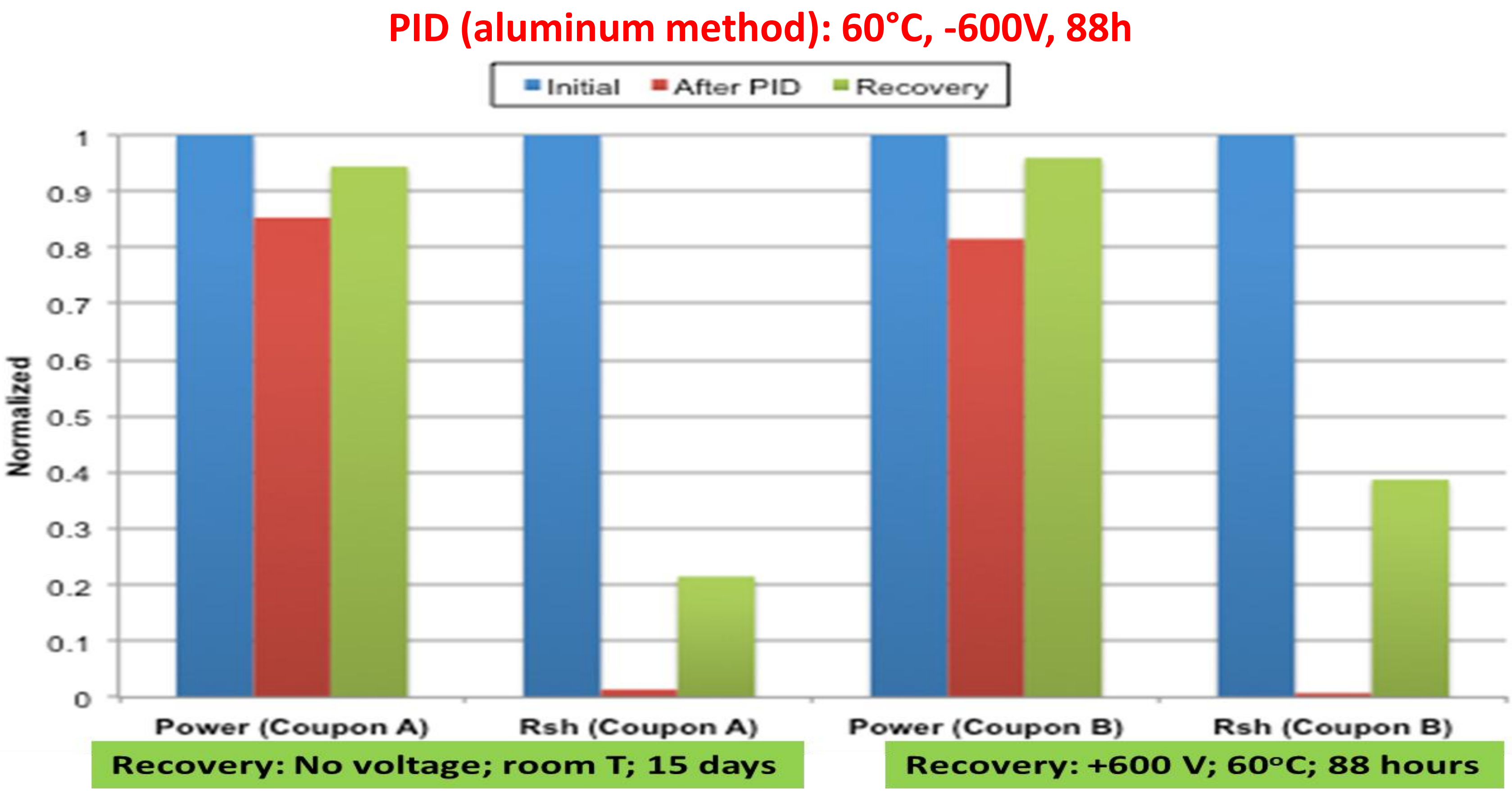
Potential induced degradation (PID) is a major degradation issue in humid/rainy locations



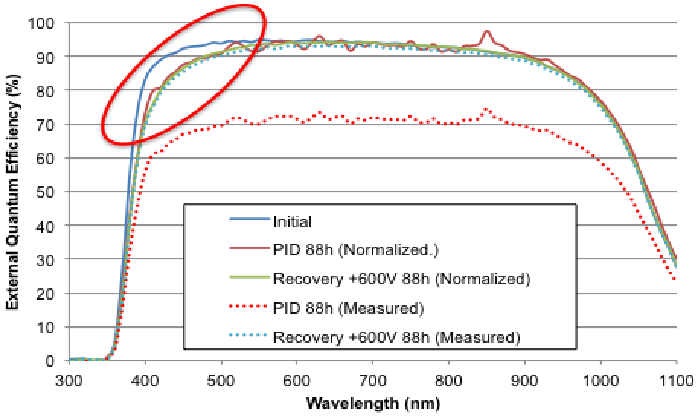




PID: Not fully recovered



- **Only about 96% recovered**
- **Reponses from blue photons are not recovered**



Source: J. Oh et al (ASU-PRL), IEEE PVSC 2014 (submitted)

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Summary

- Differences between durability and reliability losses are defined and the definitions have been applied in the outdoor evaluations
- Importance of durability for bankability is explained
- A systematic outdoor durability evaluation approach to determine climate specific degradation rate is presented
- A few key indoor durability evaluations are presented

Theses of ASU-PRL students can be freely downloaded at:

repository.asu.edu

(search under "TamizhMani")

Thanks for your attention!