Degradation Rates, Safety Failures and Reliability Failures of Fielded PV Modules: Lessons Learned in Hot-Dry Desert Climates

ARIZONA STATE UNIVERSITY
PHOTOVOLTAIC RELIABILITY LABORATORY

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Thanks to the hard work of ASU-PRL staff and students!

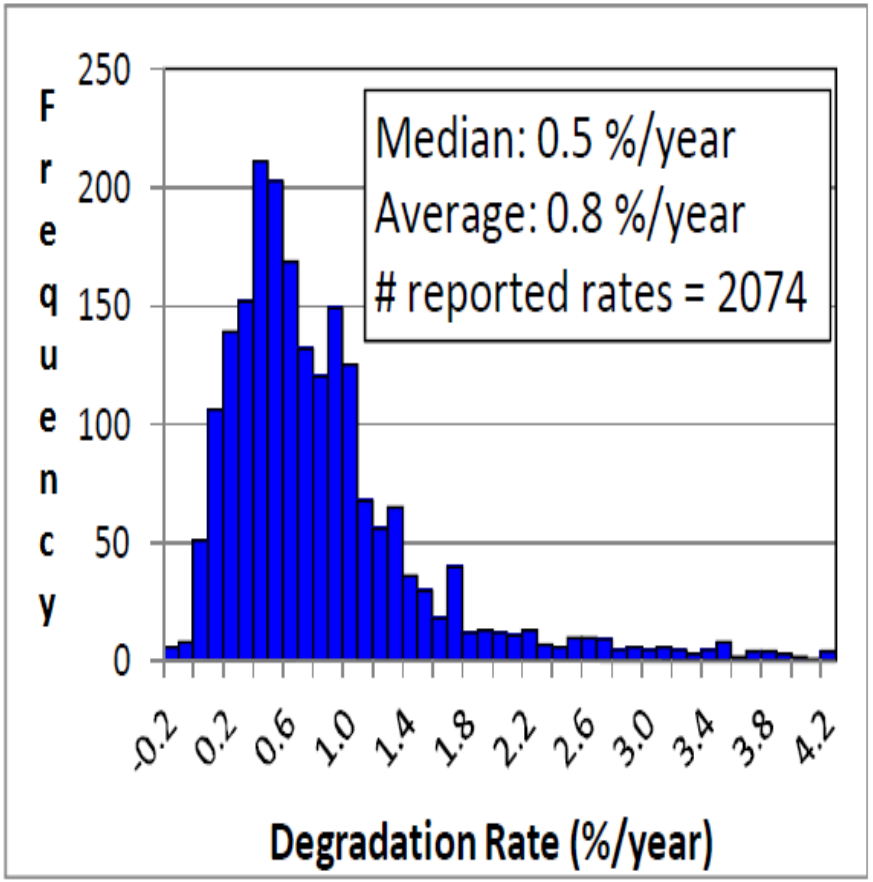
Objectives

PV power plant evaluations by ASU-PRL are performed with several objectives in mind. Two of the major objectives of this presentation are:

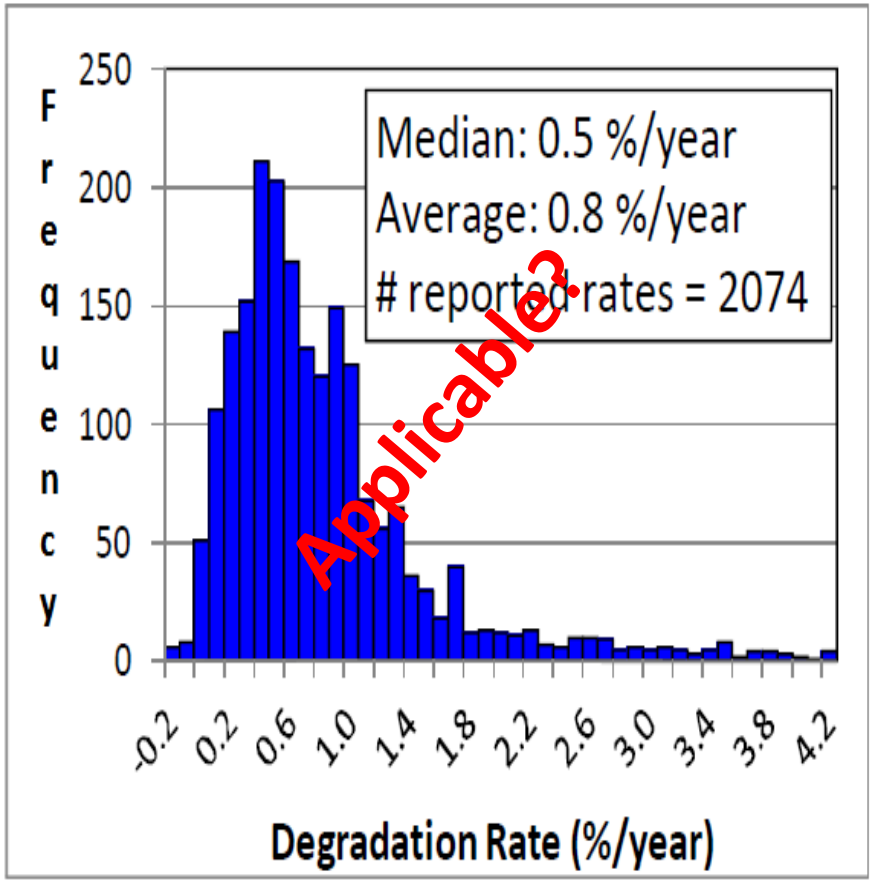
- Objectives 1: Show the degradation rate histograms for hot-dry desert climates
- Objectives 2: Show the distribution/ratio between safety failures, reliability failures and durability issues for hot-dry desert climates

Objectives 1: Show the degradation rate histograms for hot-dry desert climates

Distribution: Global Sites

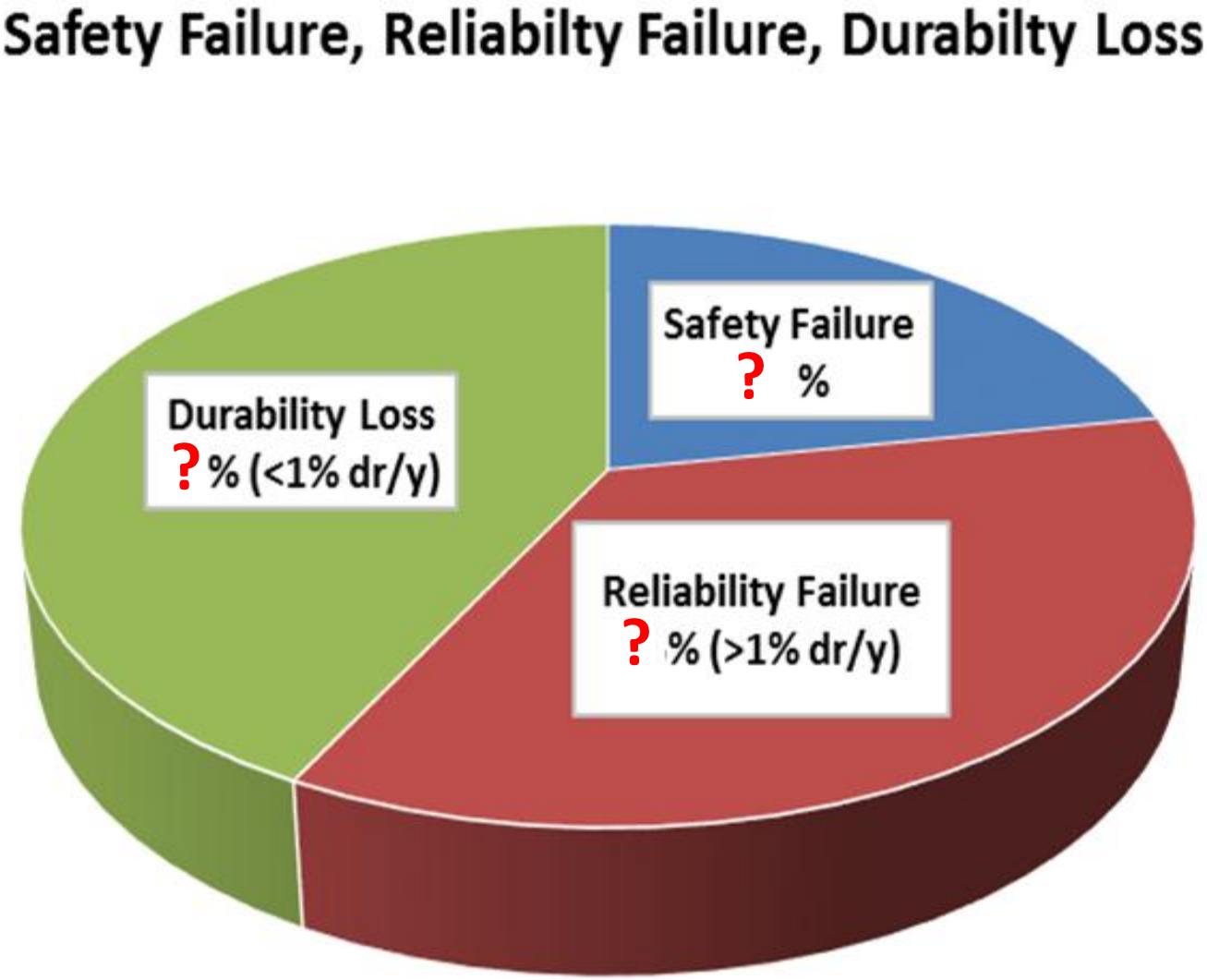


Distribution: Hot-Dry Climates



Source: Jordan and Kurtz, NREL

Objectives 2: Show the distribution/ratio between safety failures, reliability failures and durability issues for hot-dry desert climates



Presentation Outline

- Importance to stakeholders
  - Reliability evaluations
- Definitions (from users perspectives)
  - Safety failures, reliability failures and durability/degradation losses
- Approach of ASU-PRL
  - Quantitative determination of safety failures, reliability failures and degradation rates of aged PV power plants
- Results
  - Safety failures and their rates, reliability failures and their rates and degradation rate distribution
  - Primary parameter loss (Imax and/or Vmax) causing Pmax loss
- Conclusions

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Reliability Evaluation: Importance to Stakeholders

Project Developer Perspective 1: To decrease levelized cost of energy by increasing "h" value in $/kWh

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

$/kWh = Bankability

Performance → **$/kW**

Safety, Reliability and Durability → **h**

"$/kW" dictated by:

- **Materials and process cost per unit area**
- **Module efficiency per unit area**

"h" dictated by:

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

SF = Safety Failure (Qualifies for safety returns)

RF = Reliability Failure (Qualifies for warranty claims)

DL = Durability Loss with or without Cosmetic Defects (Does not qualify for warranty claims)

Reliability Evaluation: Importance to Stakeholders

Project Developers Perspective **2**: To secure low interest loan without risk premium adders

Interest Rate

=

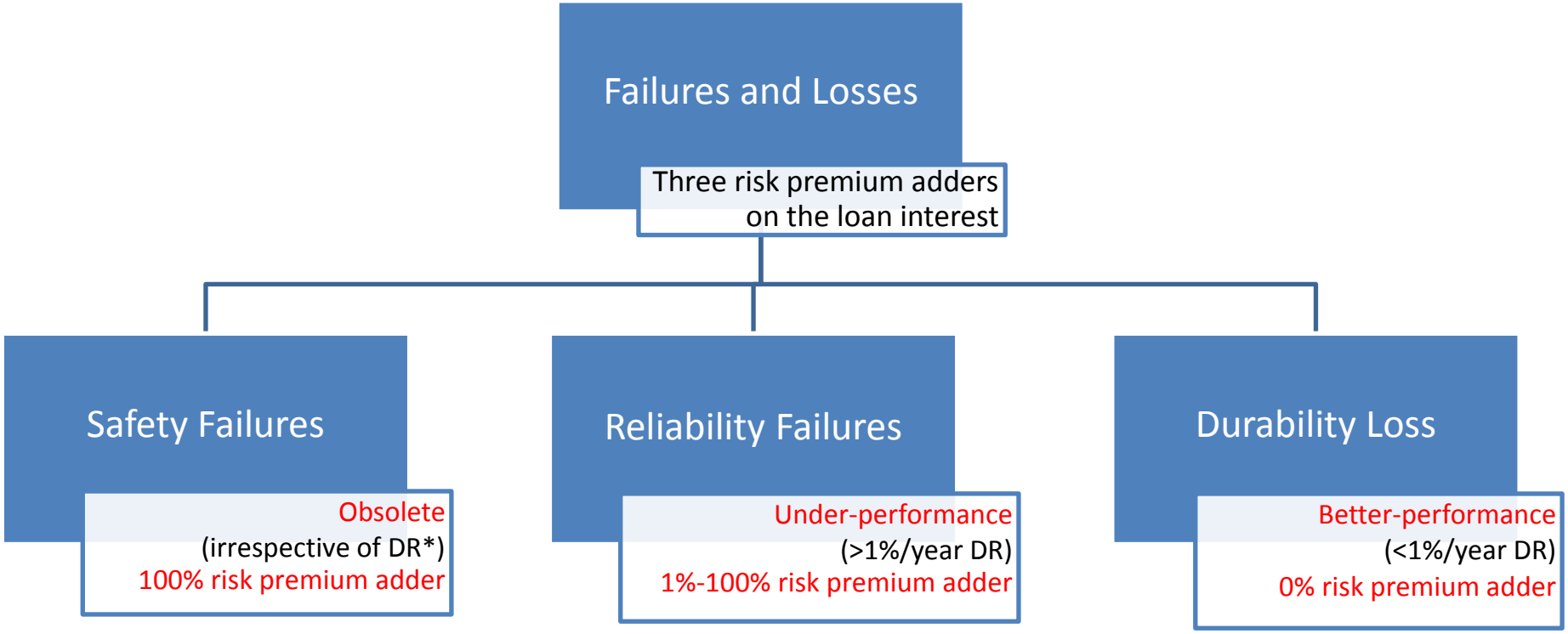
Interest Rate @ Zero Risk

+

Risk Premium Rate

Reliability Evaluation: Importance to Stakeholders

Project Developers Perspective **2**: To secure low interest loan without risk premium adders



*DR = Degradation Rate

Source: ASU Photovoltaic Reliability Laboratory (ASU-PRL)

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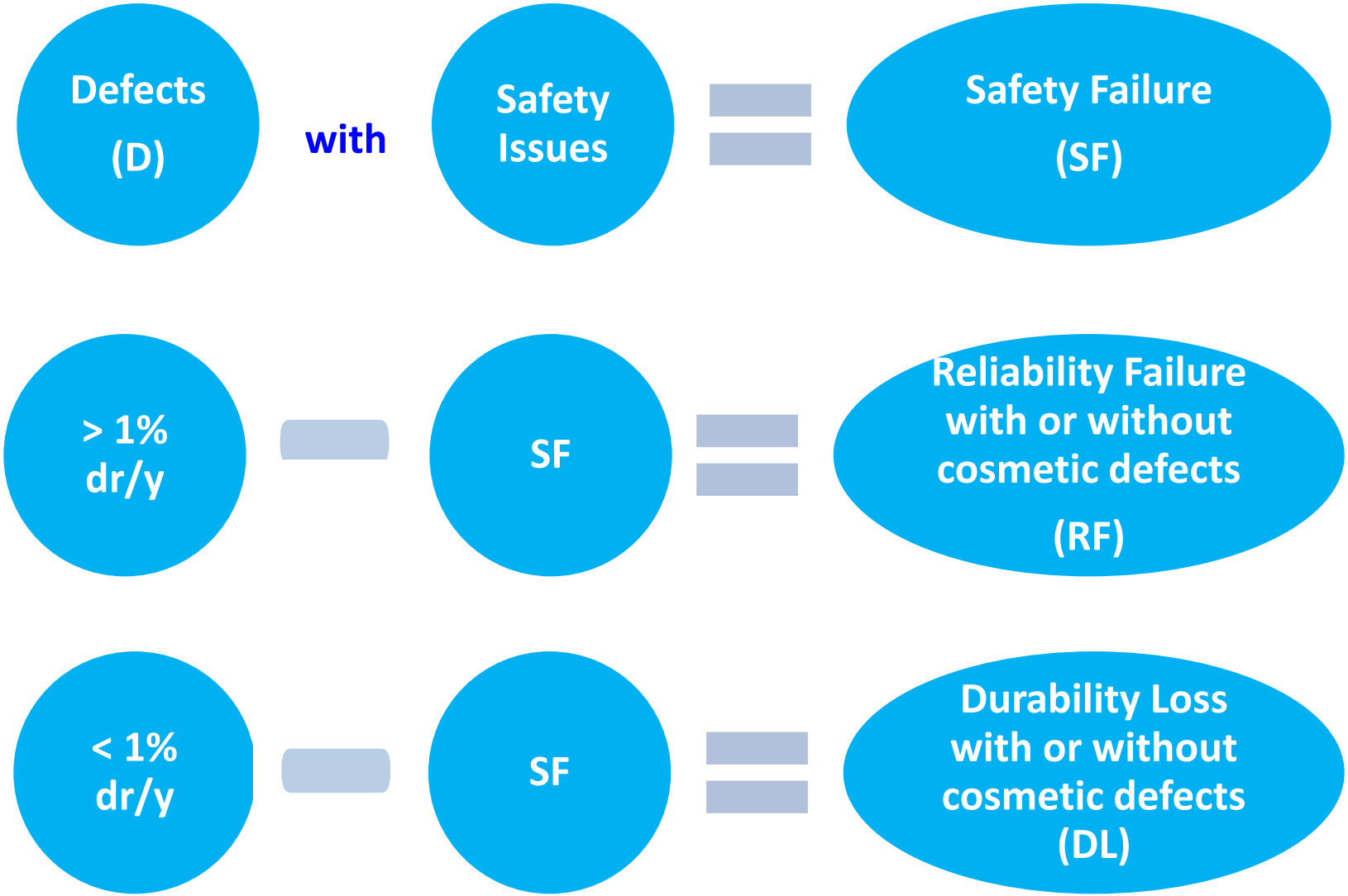
ASU-PRL's Definition of Failures and Degradation



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PV Power Plant Evaluation:

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

Review:
Module Construction, Full I-V curves (STC and LowEs), Previous Reports, System Layout, Metered kWh and Weather Data

Visual Inspection:
All modules per NREL checklist

Megger Tests:
All safety failed modules

Thermal Imaging:
All modules

IV & Megger Tests:
All hotspot modules

Diode Test:
All modules

IV & Megger Tests:
All diode-failed modules

Safety and Reliability Evaluation
Primary Goal: Identification of Safety Failures (SF) and Reliability Failures (RF)

ASU PRL

Durability and Reliability Evaluation
Primary Goal: Identification of degradation rates (DR)
[Reliability Failure (RF) = if DR>1%/y; Durability Loss (DL)= if DR<1%/y)]

I-V Test and SunEye:
All strings (before cleaning)

I-V Test:
All modules in the best, worst and median strings (before cleaning)

I-V Test
(1000, 800 and 200 W/m²):
All modules in the best strings (after cleaning)

PID Current Test:
All modules in the best strings (after cleaning)

Cell-Crack Test:
All modules in the best strings (after cleaning)

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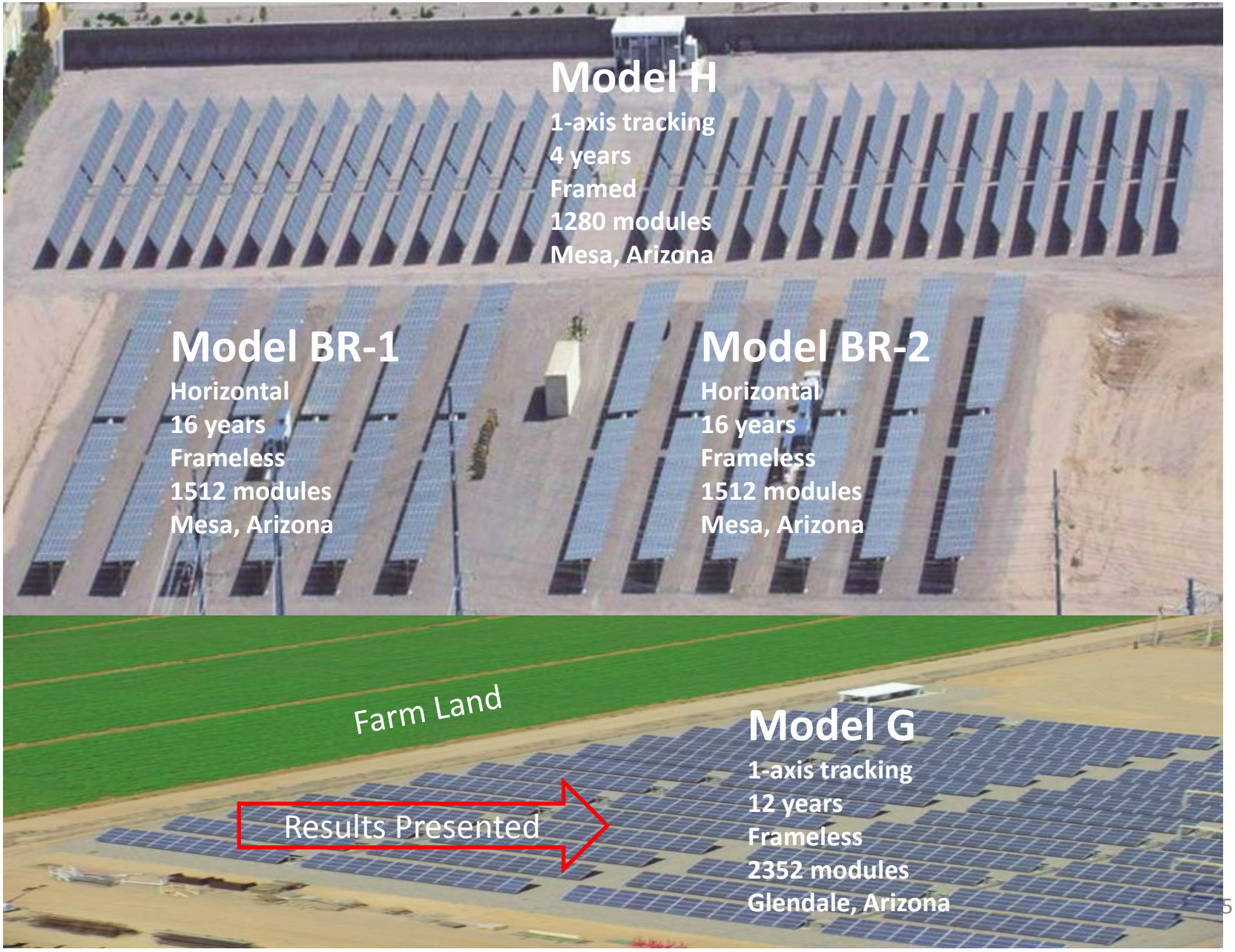
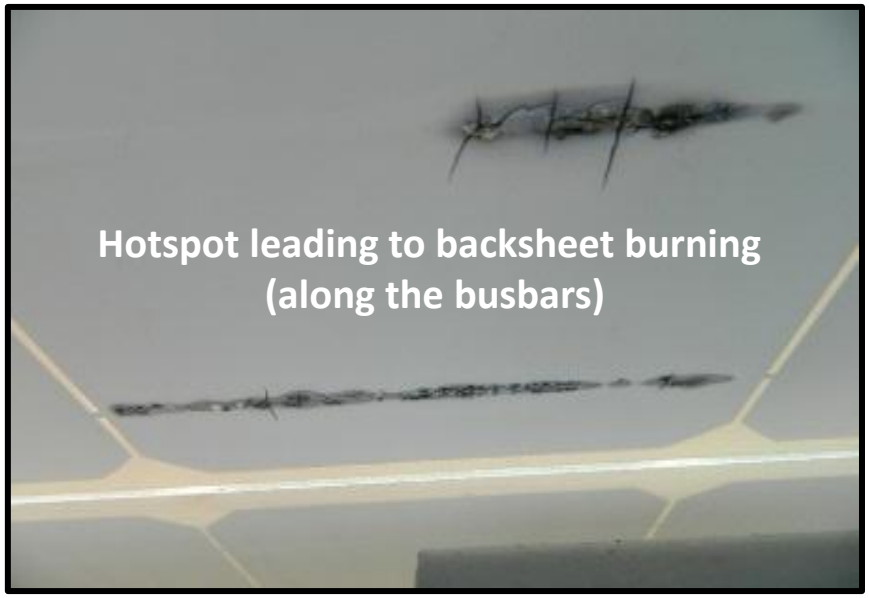
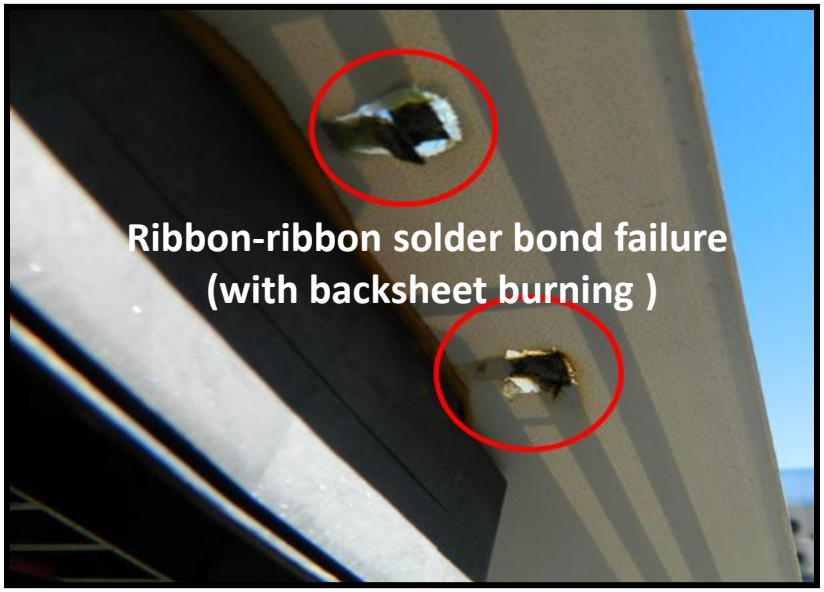
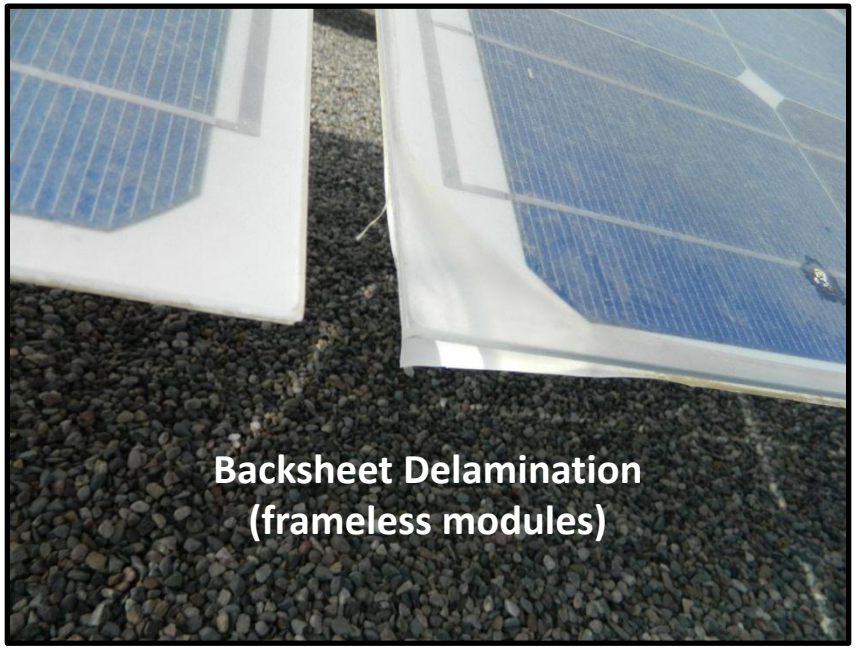
PV Power Plants Evaluated *(mono-Si; Glass/Polymer; 6656 modules)*

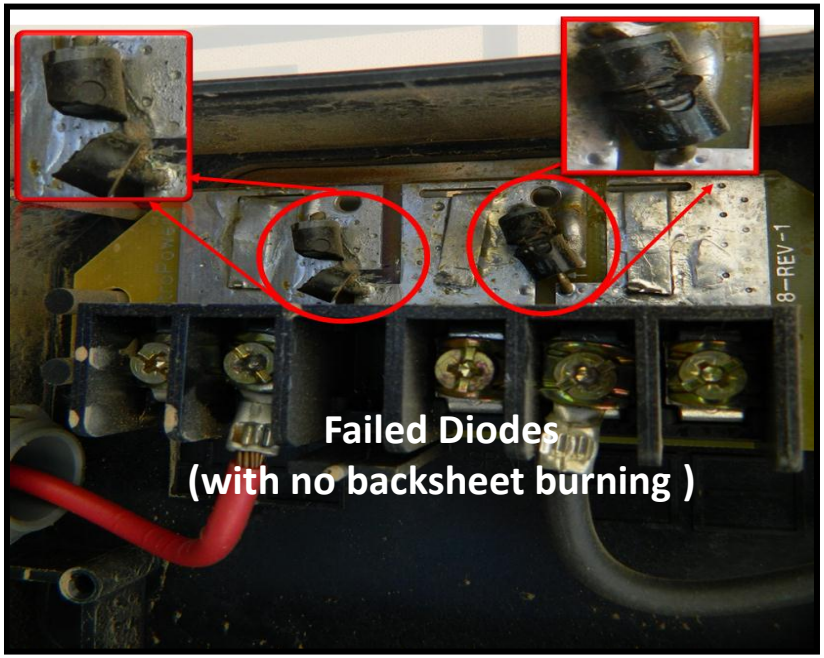


Safety Failures (*Model G*)



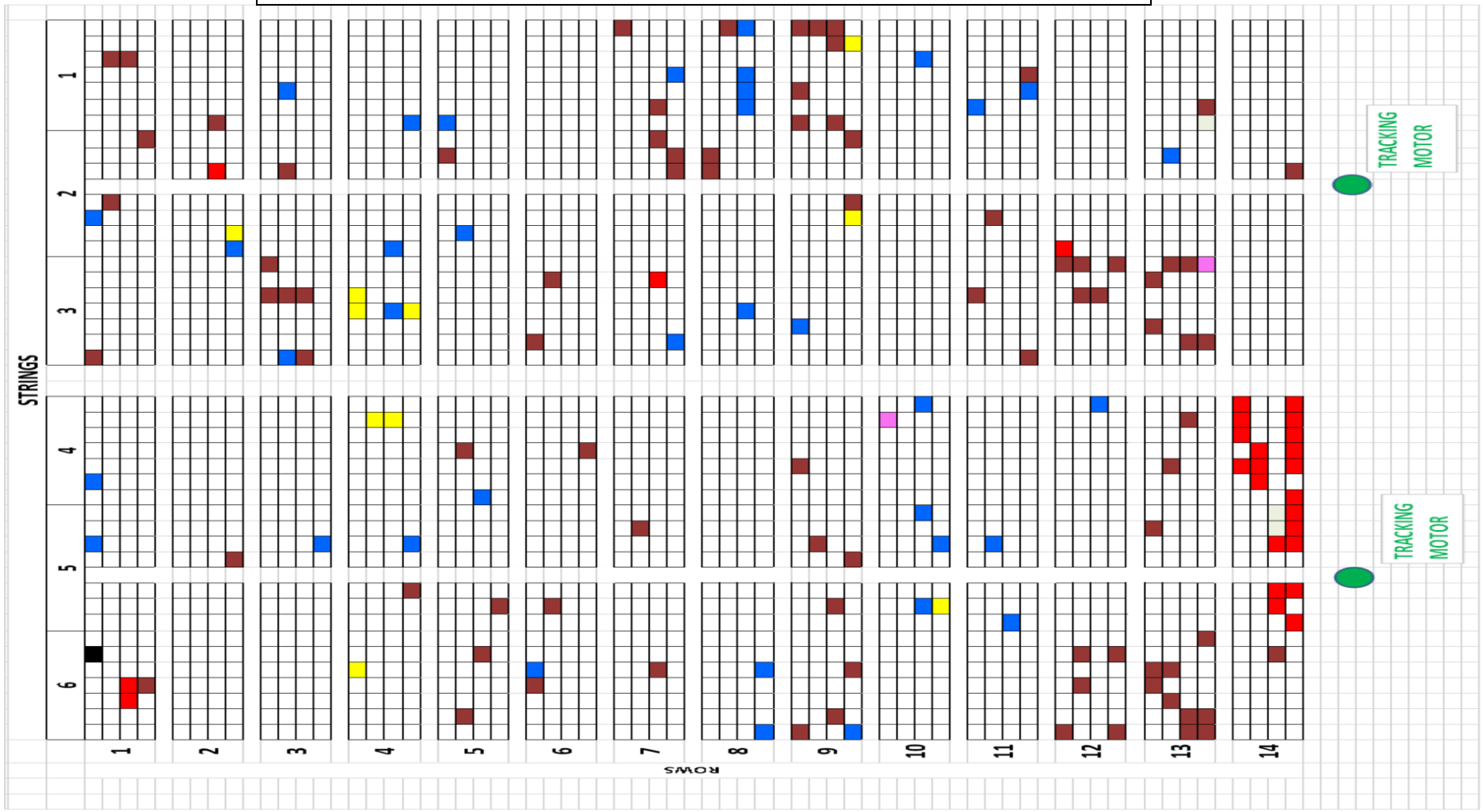






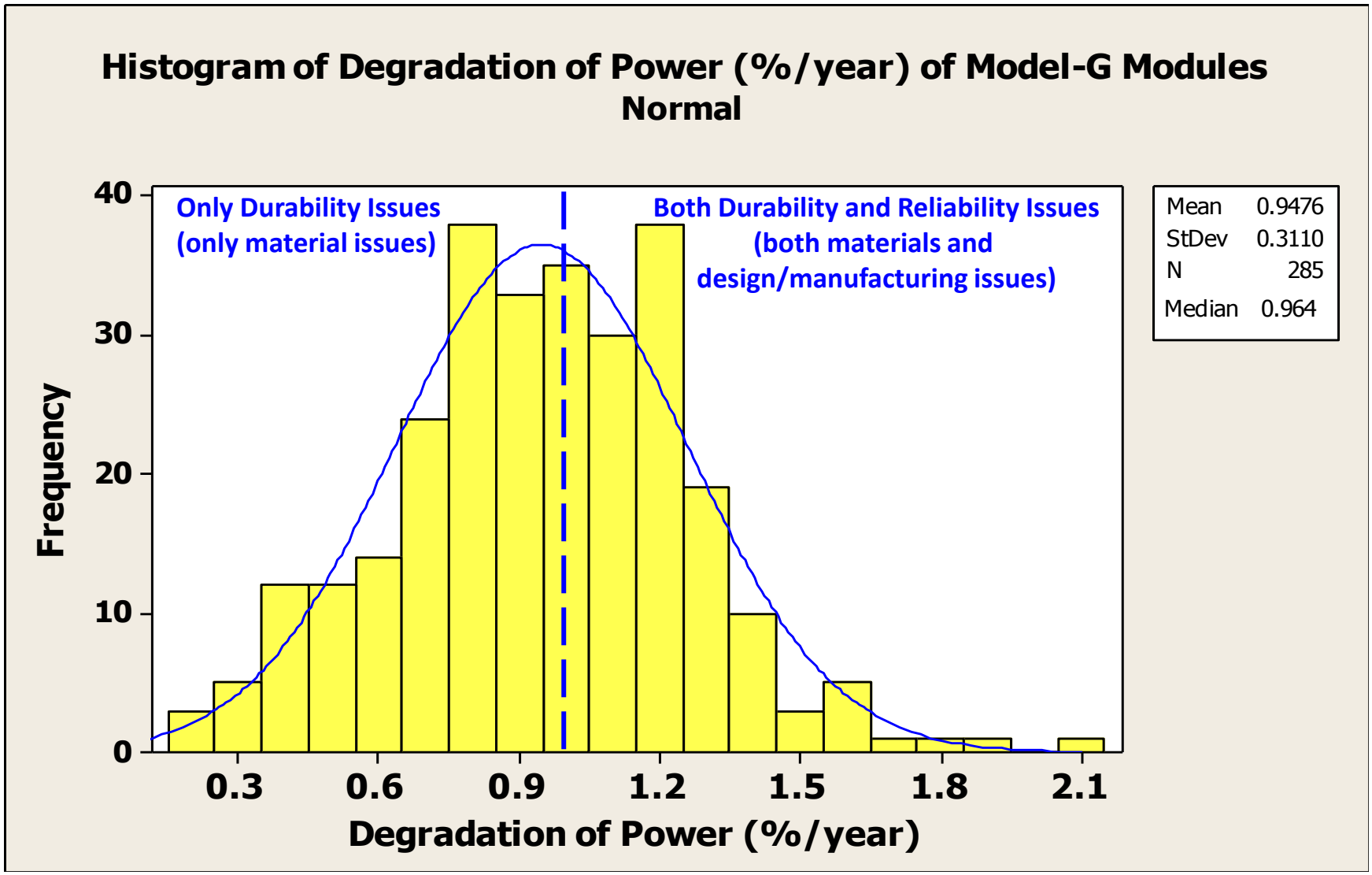
Mapping of Safety Failures (*Model G*)

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)

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

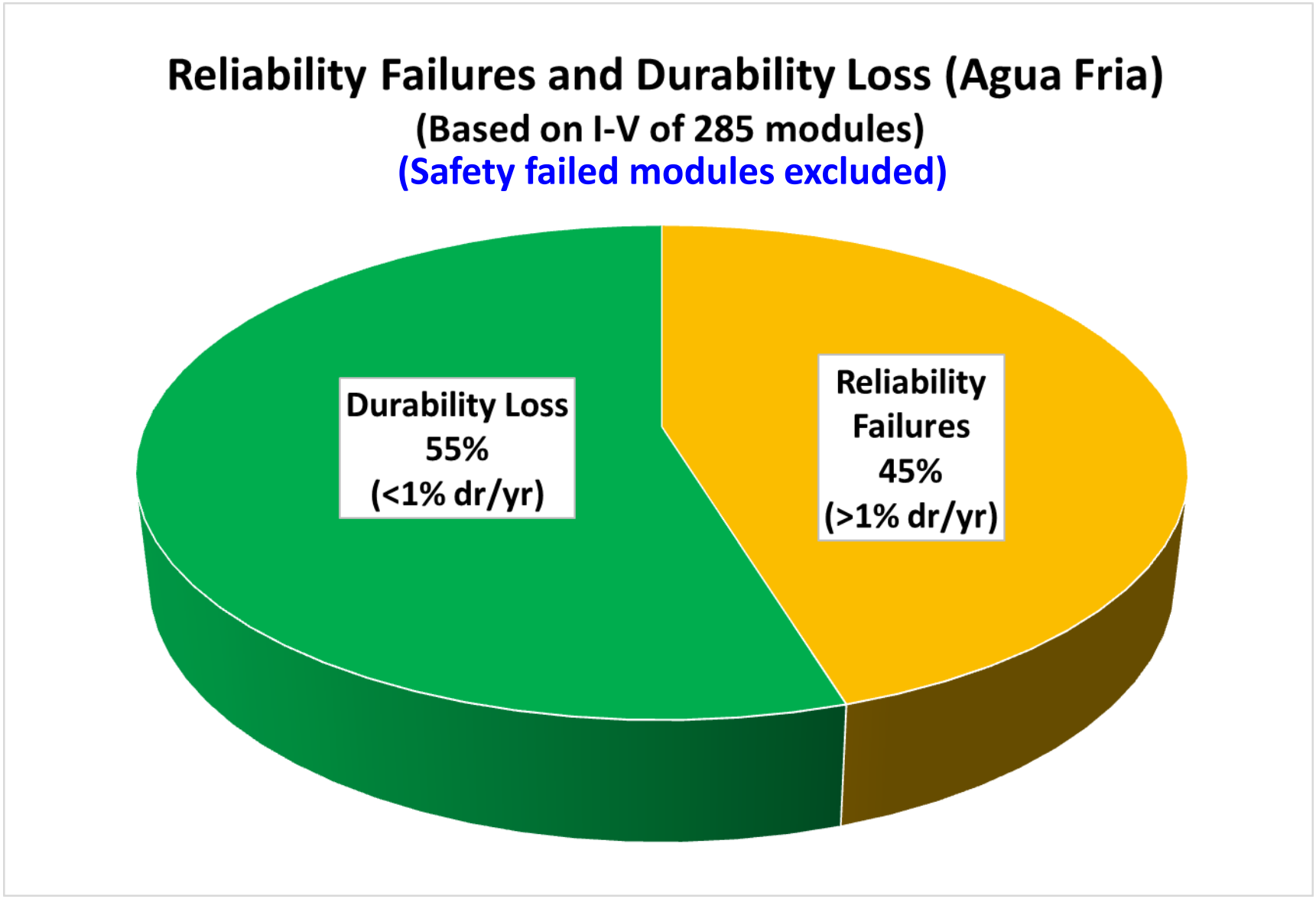


Total number of modules = 285 (safety failed modules excluded)

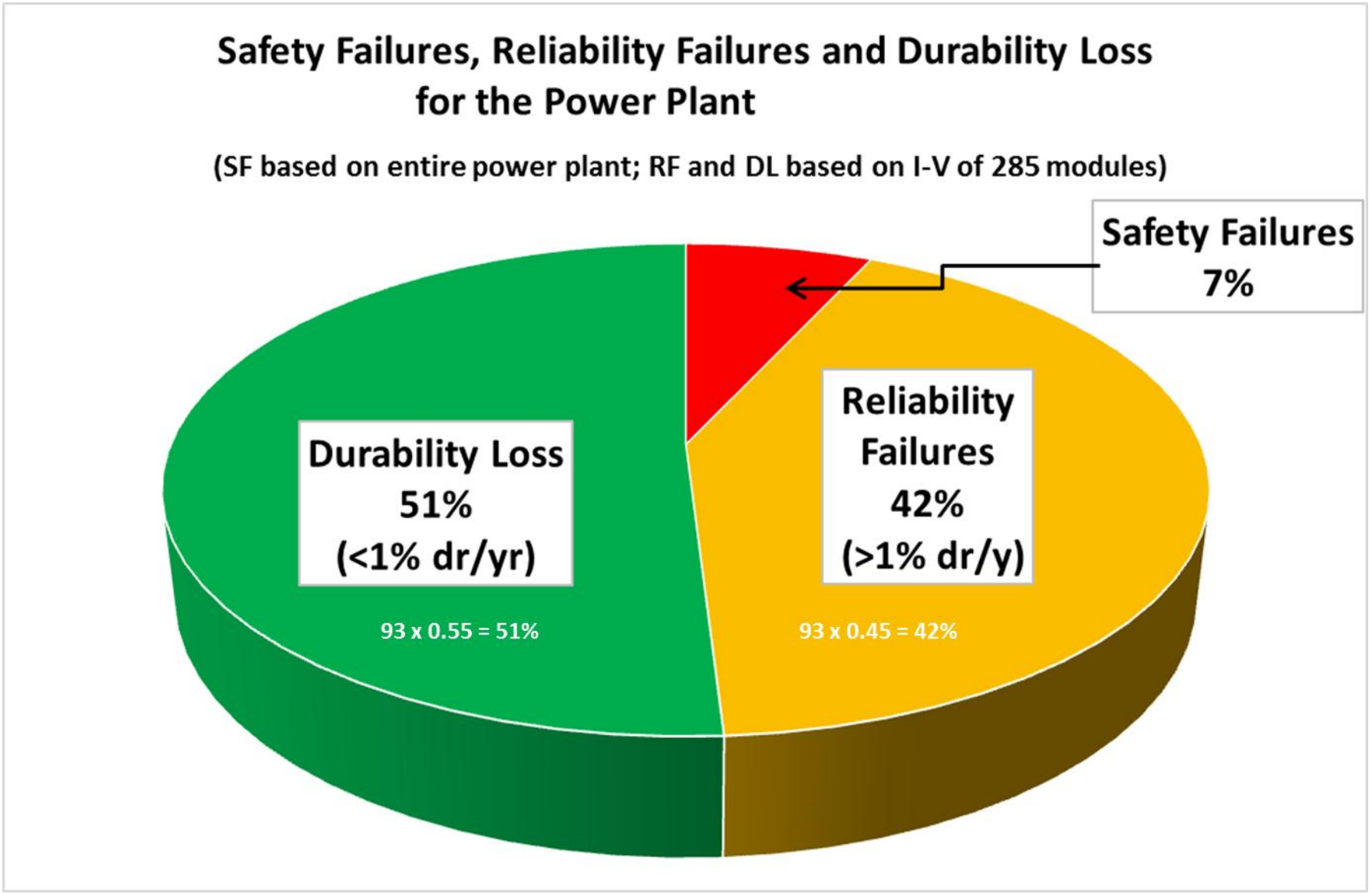
Mean degradation = 0.95%/year

Median degradation = 0.96%/year

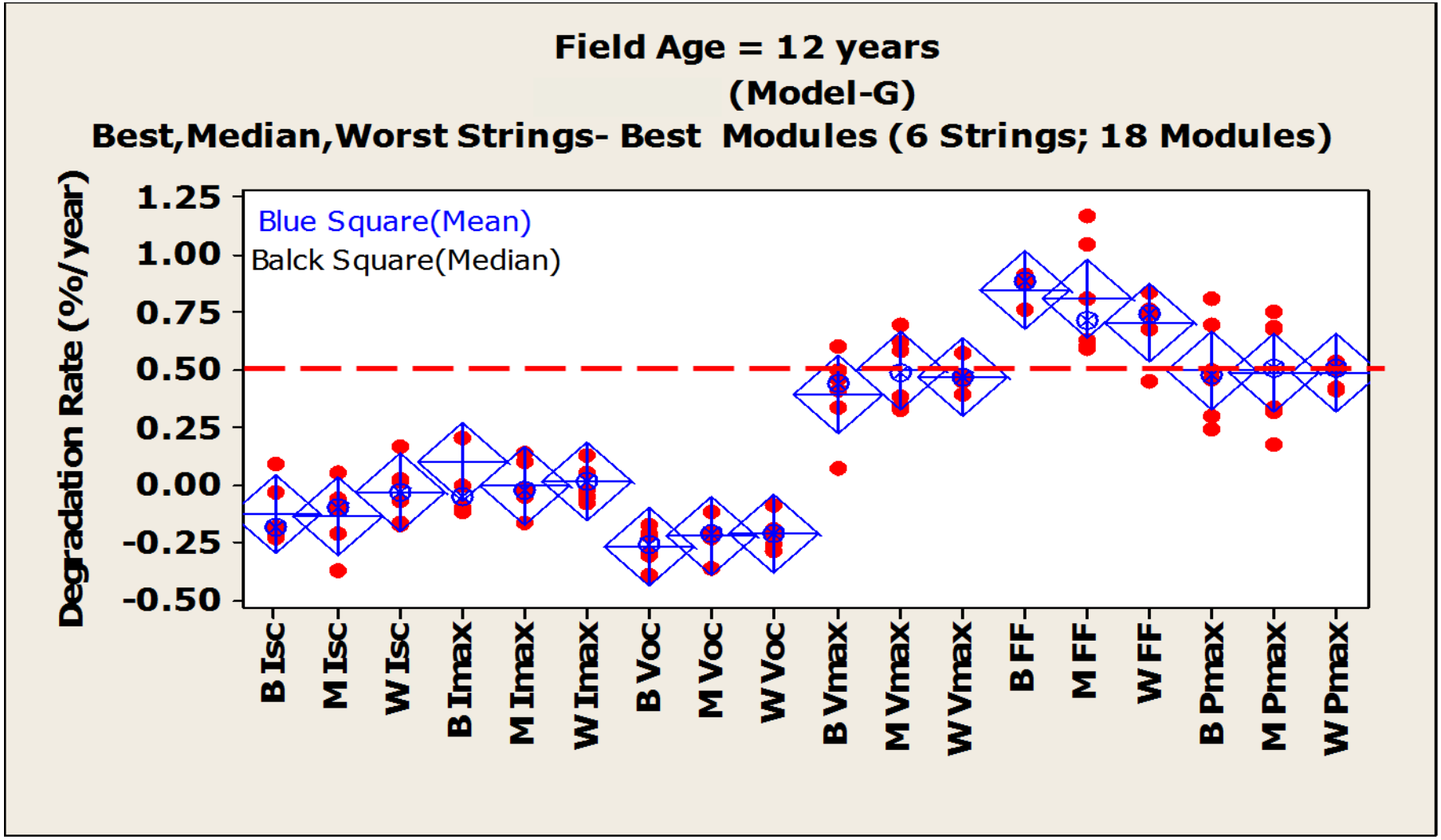
Distribution of Reliability Failures and Degradation Losses (*Model G*)



Distribution of Safety Failures, Reliability Failures and Degradation Losses (*Modle G*)



Best Modules Experienced Only Durability Issues (*Model G*)



Pmax loss → FF loss → Vmax loss → Rs increase

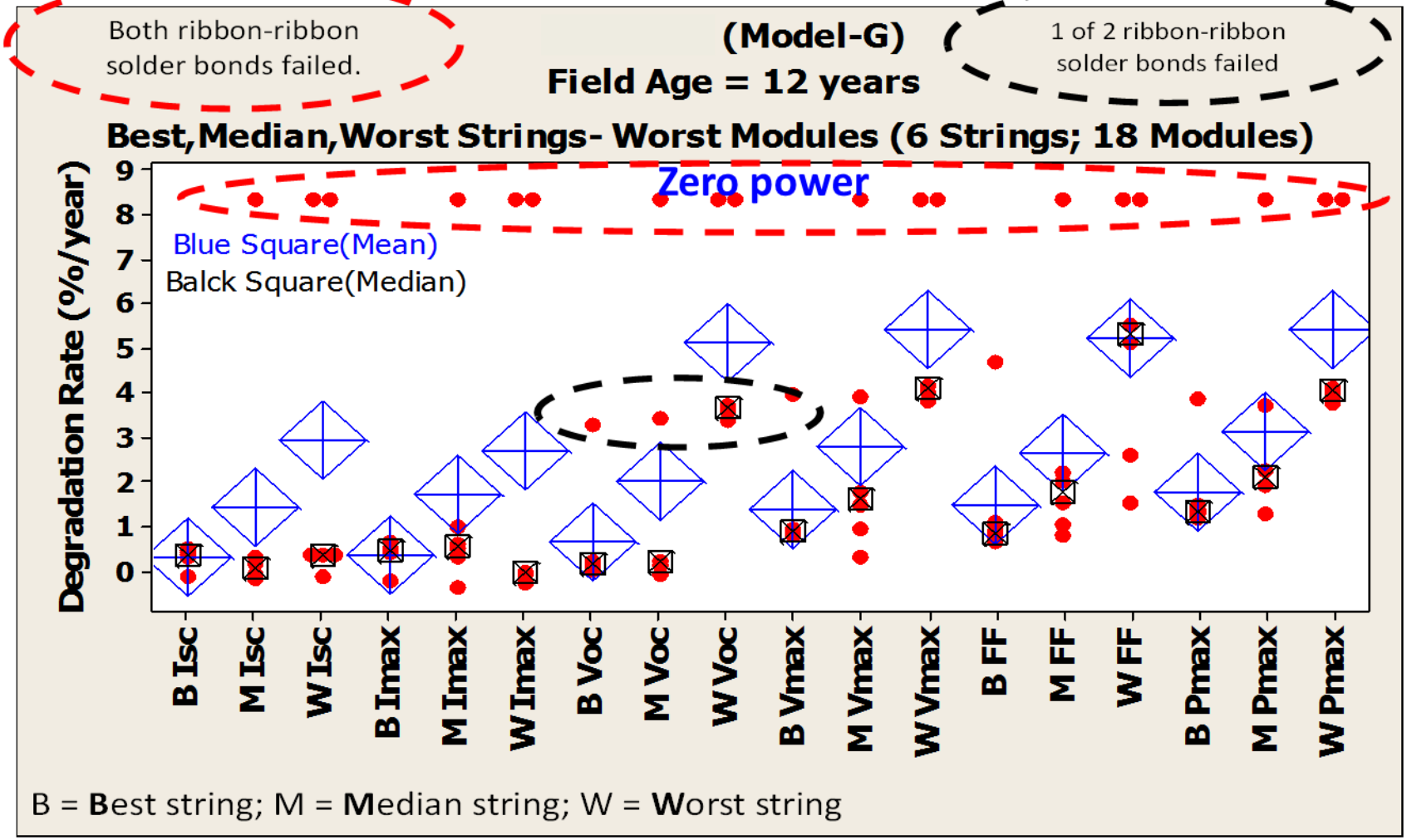
BEST modules = 18 (safety failed modules excluded)

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*)



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

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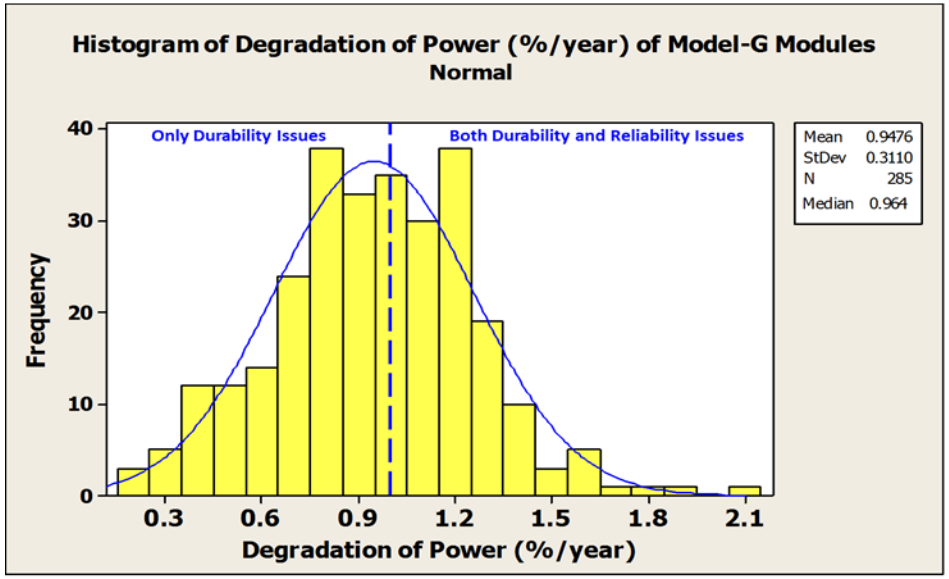
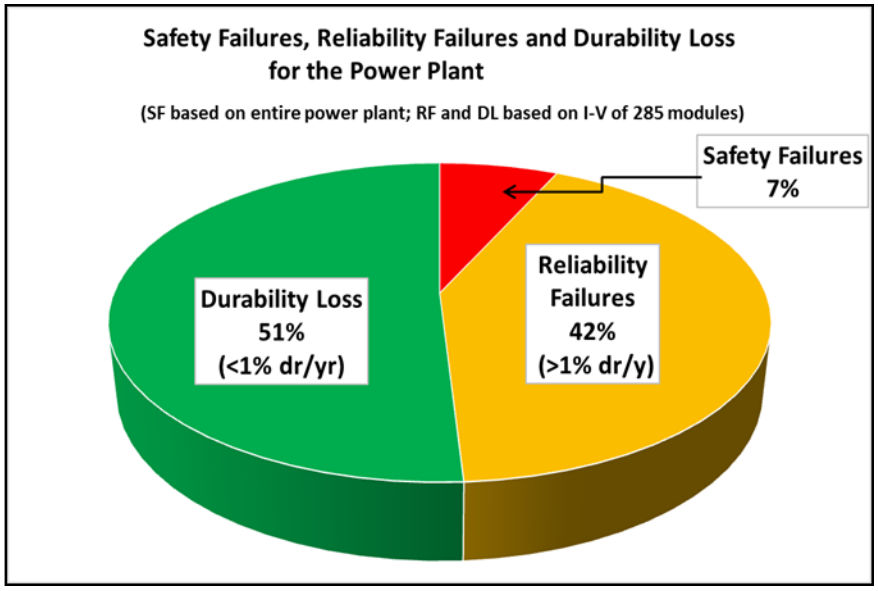
Conclusions: Hot-Dry Desert Climates





- Median degradation rate = 0.5%/year if only intrinsic (wear out) mechanism is operating and 0.96%/year if both intrinsic and extrinsic mechanisms are operating

- Primary safety failure mode is the ribbon-ribbon solder bond failures/cracks leading to backskin burning.

- Primary degradation mode and reliability failure mode may potentially be attributed to thermo-mechanical solder bond fatigue (cell-ribbon and ribbon-ribbon) leading to series resistance increase .

- 7% of the modules qualify for the safety returns under the typical 20/20 warranty terms
- 42% of the modules qualify for the warranty claims under the typical 20/20 warranty terms
- 51% of the modules are meeting the typical 20/20 warranty terms

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