

# Results from the Second International Module Inter-comparison

S. Rummel,<sup>1</sup> A. Anderberg,<sup>1</sup> K. Emery,<sup>1</sup> D. King,<sup>2</sup> G. Tamizhmani,<sup>3</sup>  
T. Arends,<sup>3</sup> G. Atmaram,<sup>4</sup> L. Demetrius,<sup>4</sup> W. Zaaiman,<sup>5</sup> N. Cereghetti,<sup>6</sup>  
W. Herrmann,<sup>7</sup> W. Warta,<sup>8</sup> F. Neuberger,<sup>8</sup> K. Morita,<sup>9</sup> and Y. Hishikawa<sup>10</sup>

<sup>1</sup>National Renewable Energy Laboratory (NREL), USA

<sup>2</sup>Sandia National Laboratories (SNL), USA

<sup>3</sup>PV Testing Laboratory-Arizona State University (PTL-ASU), USA

<sup>4</sup>Florida Solar Energy Center (FSEC), USA

<sup>5</sup> European Commission, Directorate General -

Joint Research Centre, (IES-RE-ESTI), European Union

<sup>6</sup>Laboratorio Energia Ecologia Economia (LEEE), Switzerland

<sup>7</sup>Immissionsschutz und Energiesysteme GmbH Test Centre for Energy  
Technologies (TÜV), Germany

<sup>8</sup>Institute of Solar for Energy Systems (Fraunhofer ISE), Germany

<sup>9</sup>Japan Electrical Safety & Environment Technology Laboratories (JET), Japan

<sup>10</sup>National Institute of Advanced Industrial Science and Technology (AIST), Japan

## Disclaimer and Government License

This work has been authored by Midwest Research Institute (MRI) under Contract No. DE-AC36-99GO10337 with the U.S. Department of Energy (the “DOE”). The United States Government (the “Government”) retains and the publisher, by accepting the work for publication, acknowledges that the Government retains a non-exclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for Government purposes.

Neither MRI, the DOE, the Government, nor any other agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe any privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not constitute or imply its endorsement, recommendation, or favoring by the Government or any agency thereof. The views and opinions of the authors and/or presenters expressed herein do not necessarily state or reflect those of MRI, the DOE, the Government, or any agency thereof.

# History

1987 to 1989 - PEP '87

Cells, cell in module package and module of identical type  
2 day meeting of participants, PTB issued formal report,  
1990 presented at 21 IEEE PVSC

Range Si Modules;  $I_{sc} = 2-5\%$ ,  $FF = 1-2\%$ ,  $V_{oc} = 2-5\%$

Range a-Si tandem Modules  $I_{sc} = 8\%$ ,  $FF = 2.5\%$ ,  $V_{oc} = 1\%$

Final Report analyzed data using 2 standard deviations,

$I_{sc}$  2-6% for Si, 3-10% for a-Si,  $FF$  1-2%,  $V_{oc}$  0-5%

1992 to 1994 - ASTM E1036 Interlaboratory Test Program

encapsulated cells provided, (Range in  $P_{max} \sim 5\%$ )

$P_{max}$  95 % repeatability limit (within laboratory) = 0.7%

$P_{max}$  95 % reproducibility limit (between laboratory) = 6.7%

Manufacture sponsored intercomparisons -

often only 2 labs & results usually not published.

# Goals

Evaluate differences in module IV parameters With Respect to Standard Reference Conditions between National Calibration facilities

ISO-17025 Accredited PV

Qualification or Calibration Labs

Modules Chosen to –

Identify differences in participants scope

Flat-plate, Concentrator

Single-junction, Multi-junction

Crystalline Si, Thin-film

“Typical” Quantum Efficiency supplied by the manufacturer

No reference cell is provided

Include Samples that have had measurement related problems

Bias Rate, Current Matching for Multi-junction,

Sensitivity to Spatial Nonuniformity, Tracking for concentrator



AstroPower  
S/N#200205740248  
7/30/2002

## The Sample Set - crystalline Si

mono-Si

multi-Si

720 kWh $m^{-2}$  of sunlight prior to circulation  
No significant change in modules during intercomparison  
except ~3% for amorphous Si

Siemens Solar  
S/N#460100586

# The Sample Set - CdTe & CIGS

BP Solar S/N# 0815303 8/9/2002

CdTe

Cu(Ga,In)(S,Se)

Siemens Solar CIGSS  
S/N# 310108817  
3/13/2002



BP Solarex  
S/N# 1084313  
3/13/2002

# The Sample Set - amorphous Si

a-Si/a-Si

USSC S/N#19240  
3/13/2002

a-Si/a-Si/a-Si:Ge

# The Sample Set - PEP '87 Concentrator

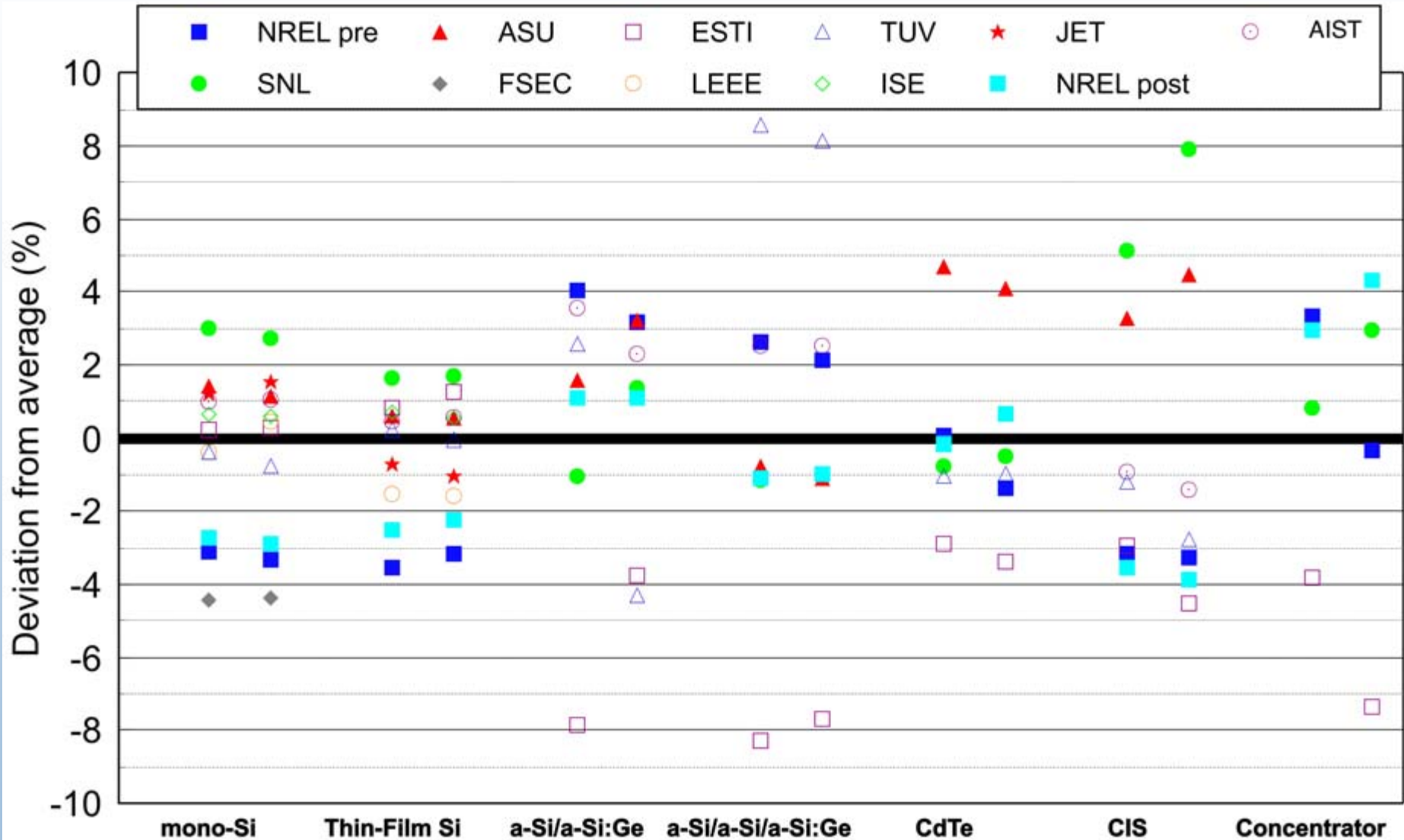


GaAs

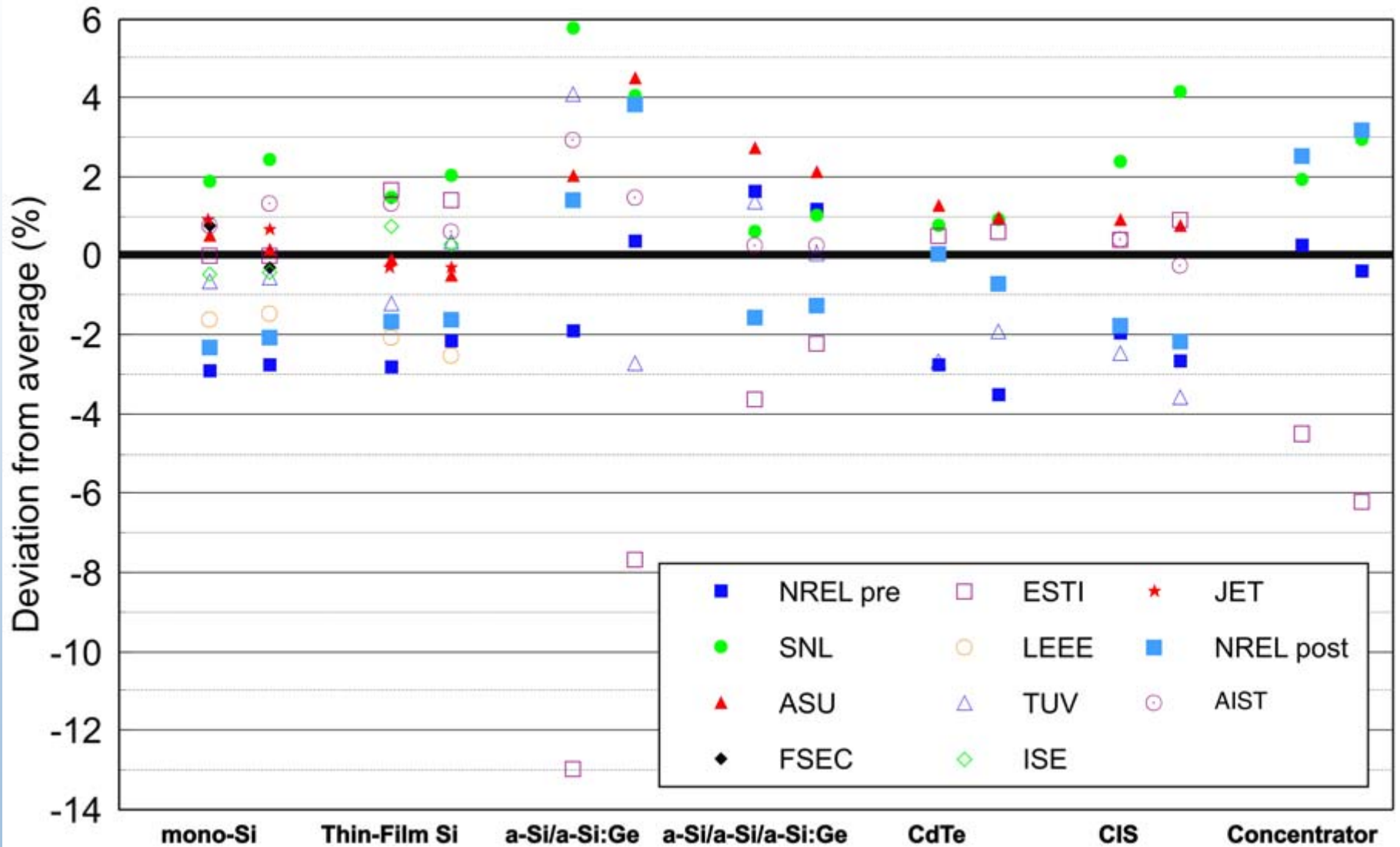
**Varian Research Center  
1000X Concentrator Module  
PTEL#1152  
10/8/2002**



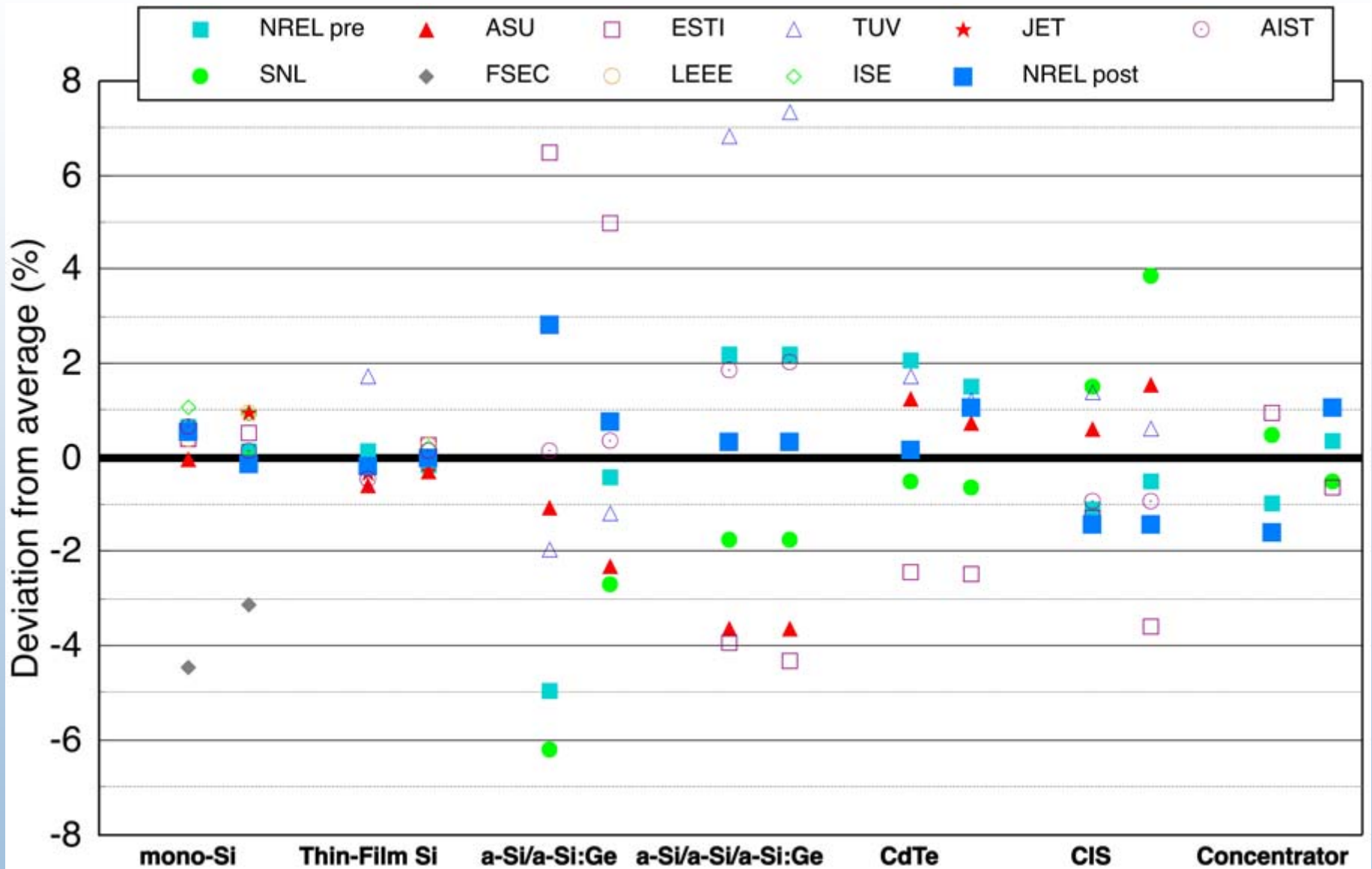
# Results - $P_{max}$ @ 25 C, 1000 $Wm^{-2}$ , IEC Global Reference spectrum



# Results - $I_{sc}$

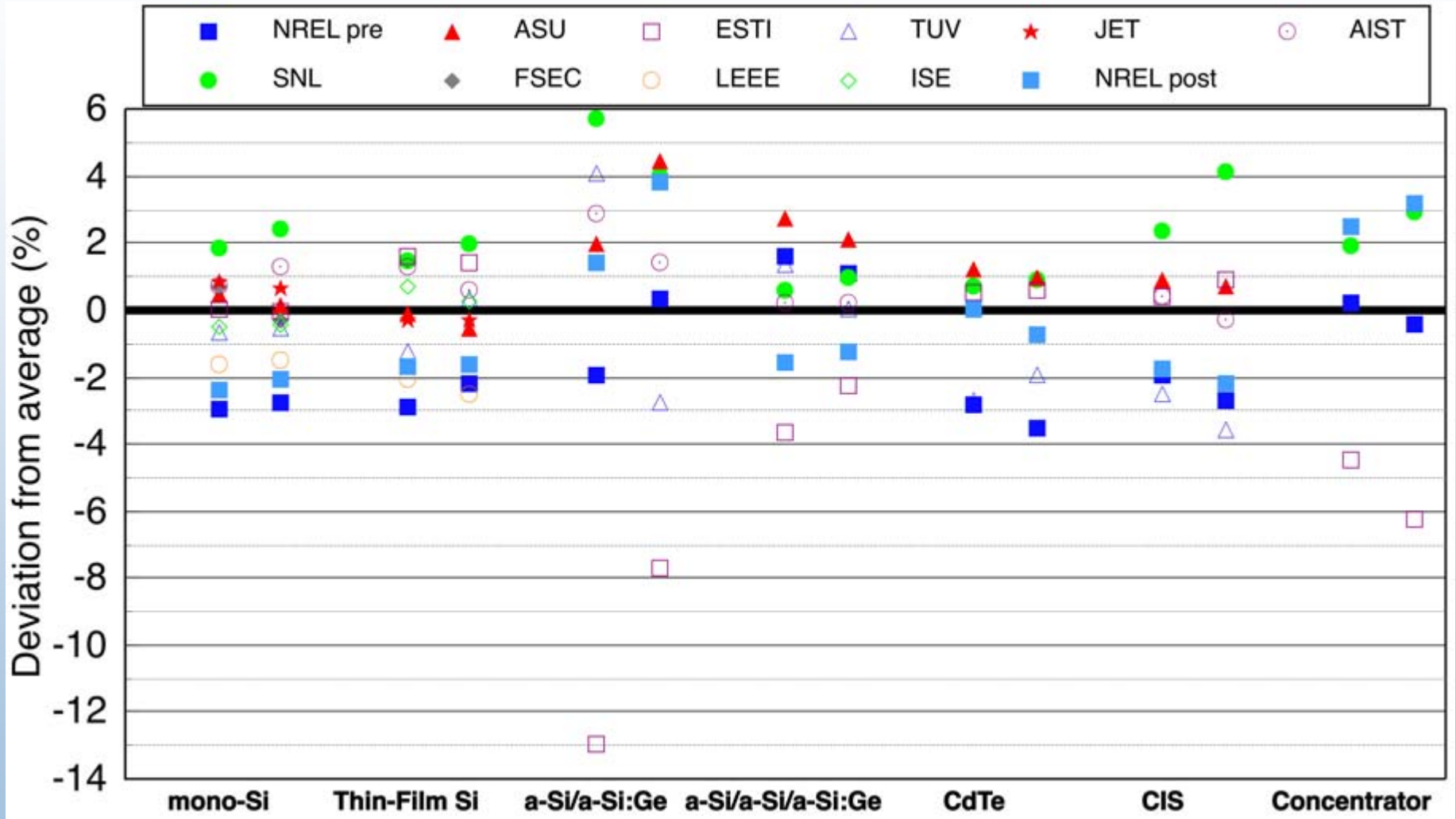


# Results - Fill Factor





# Results - Voc



# Summary

- Range in  $I_{sc}$  for Si 5%, CIS 5 & 8%, CdTe 4%,  
Multijunction range 4 to 19% depending on module.  
Not having the luxury of a matched reference cell,  
Representative cell, or the Measured Module spectral  
responsivity may be the cause of larger differences  
than previous module intercomparisons.
- Range in  $P_{max}$  for Si 6 & 7%, CIS or CdTe 8%,  
Multijunction range 7 to 17% depending on module.
- Range in  $V_{oc}$  for Si 4 to 5%. About an 8 C temperature  
range would be required to account for a 5%  $V_{oc}$   
difference.
- Several participants didn't measure concentrator or thin-  
film modules because they were outside their scope.