Solar cells in radiation environments

Application of SPENVIS for solar cell performance prediction

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Contents

- **Are radiation studies a worthwhile investment ?**
- **Improving the cost effectiveness of radiation prediction**
  - **JPL 'Equivalent fluence model' (EQFLUX in SPENVIS)**
  - ***many organisations and companies in Europe and elsewhere use this method via SPENVIS***
  - ***it has worked well historically and is available to the whole community***
  - ***Requires lots of reference data for every new cell type***
  - **NRL Displacement damage dose concept**
  - ***A potential alternative to EQFLUX that requires less test data***
  - ***see presentation by Scott Messenger***
  - **Theoretical model based on introduction of recombination centers in the solar cell**
  - ***A theoretical model, hence potentially several possible applications inside or outside SPENVIS***
  - ***see presentation by Jacques Bourgoin***

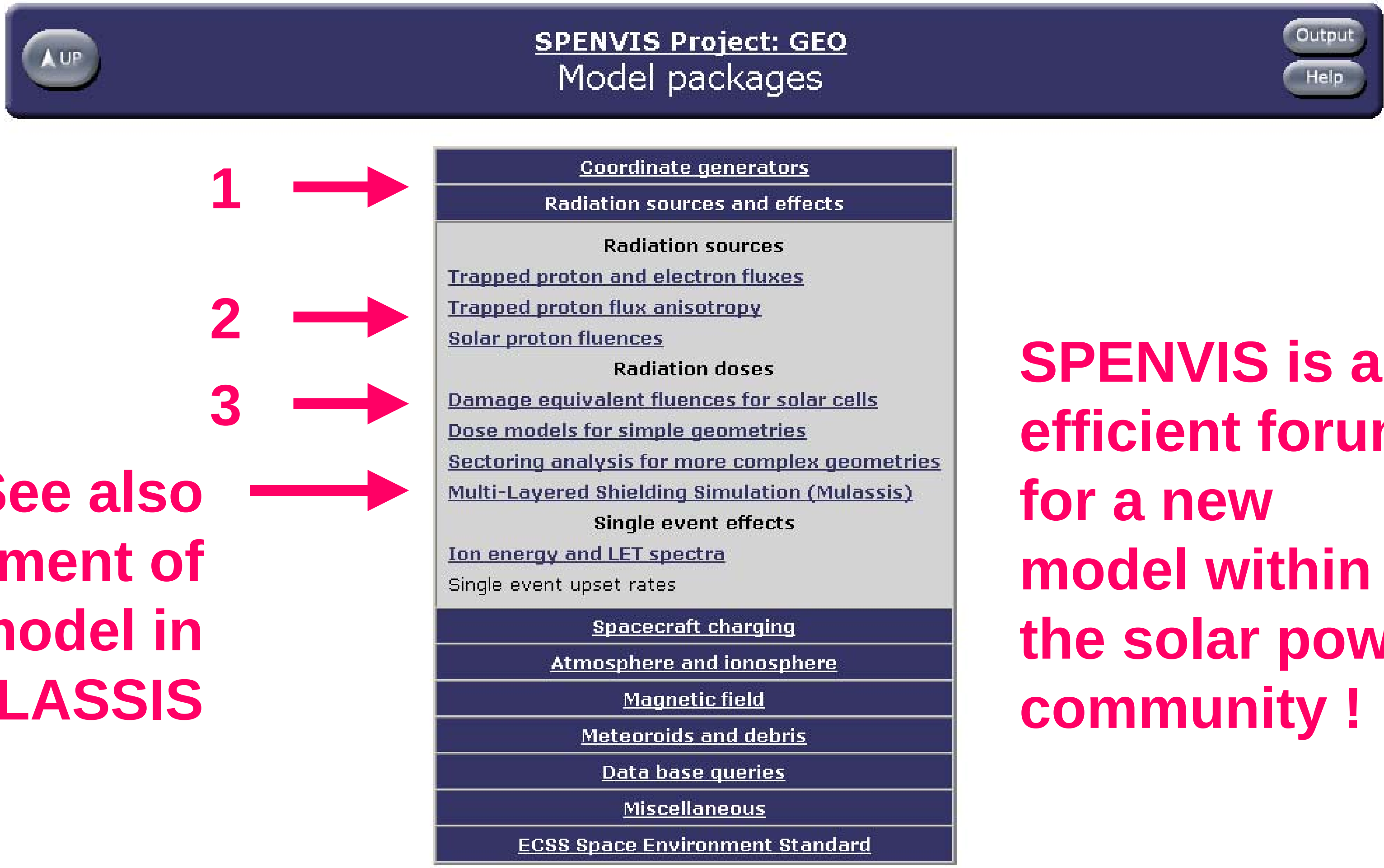
Motivation - Economics for a 10kW Solar Array

- <u>**Relative Costs (rough numbers…)**</u>
- **Cost to launch a 10kW solar array based on <u>*mass only*</u>**
  - **Say €4M (@ €30k/kg)**
  - **Note that mass is not necessarily critical if the mass of the satellite is compatible with the capacity of a designated launcher, but this is anyway a useful number…**
- **Cost of a 5% power margin based on only this number**
  - **Around €200k**
- **Cost of a radiation campaign on a new cell design**
  - **Potentially several €100k (cost of samples, radiation, measurements…)**
  - ***This is equivalent to the profit on sales of a lot of solar cells…. !!***
  - ***Cost of qualification is significant, but still a good investment***
- <u>**Conclusions**</u>
- ***Extra power margin is very expensive !!***
- **We would like to reduce the cost of ground testing, but <u>NOT</u> at the expense of the accuracy of power prediction**
- **A radiation study costing up to several €100k which improves 'end of life' power prediction is likely to pay for itself very quickly….**

Radiation damage to solar cells

- **Most solar cell degradation in space is mostly caused by displacement damage**
- **Atomic displacement introduces ‘recombination centers’ which reduce the probability that an electron will contribute to the solar cell current**
- **Space solar cells are protected by a coverglass to reduce the radiation dose (mostly by slowing down the whole proton spectrum and cutting out low energy protons)**
- **For this reason, we tend to perform ground tests on unprotected solar cells with protons and electrons in the range 0.1MeV to 10MeV**

Implementation in SPENVIS (using EQFLUX)



1

2

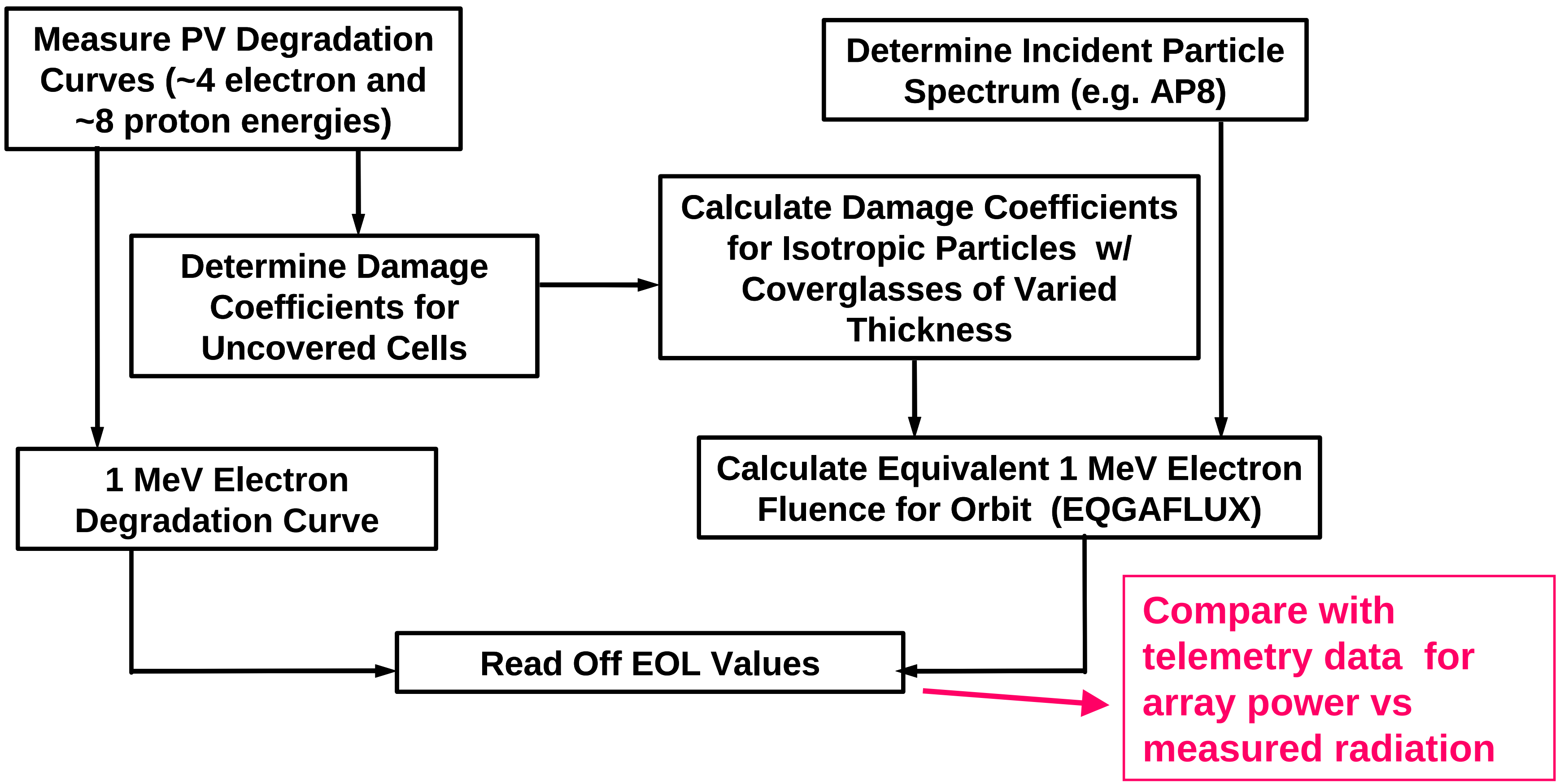
3

See also development of NIEL model in MULASSIS

SPENVIS is an efficient forum for a new model within the solar power community !

JPL Equivalent Fluence Method

Improvement of any step makes a difference to the end result….

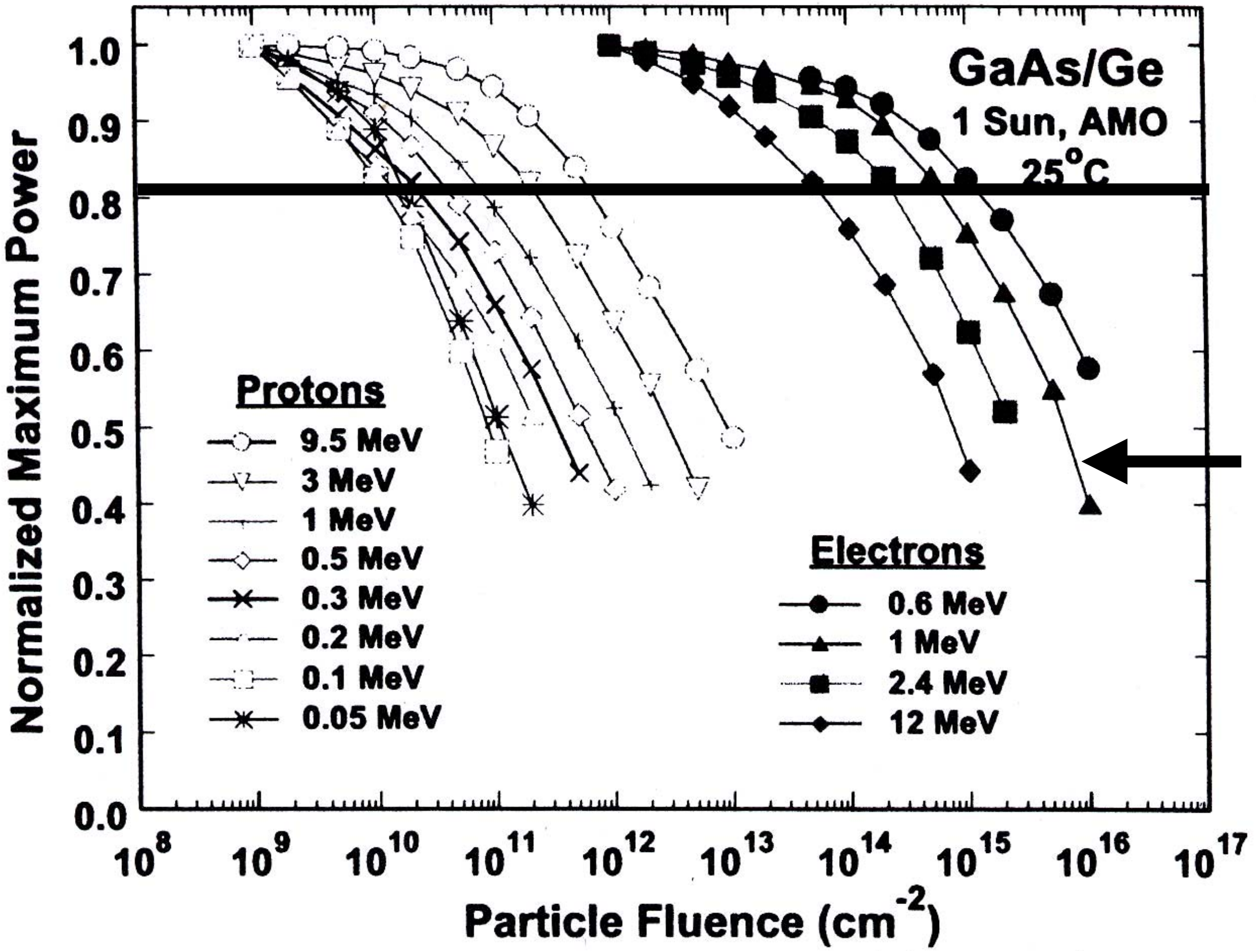


- *From S.R.Messenger et al, Progress in Photovoltaics 9, 103 (2001)*

- **How can we make 'end of life' performance prediction more cost effective ?**
  - ***Improve knowledge of the environment***
  - ***Understand and model the interactions between the environment and the device***
  - ***Acquire appropriate ground test data***
  - ***Compare predictions with in-flight data from solar arrays and radiation monitors***

Establishment of Relative Damage Coefficients

$P/P_0 = 1 - A.\log(1 + \Phi / B)$: **See presentation by Jacques Bourgoin**

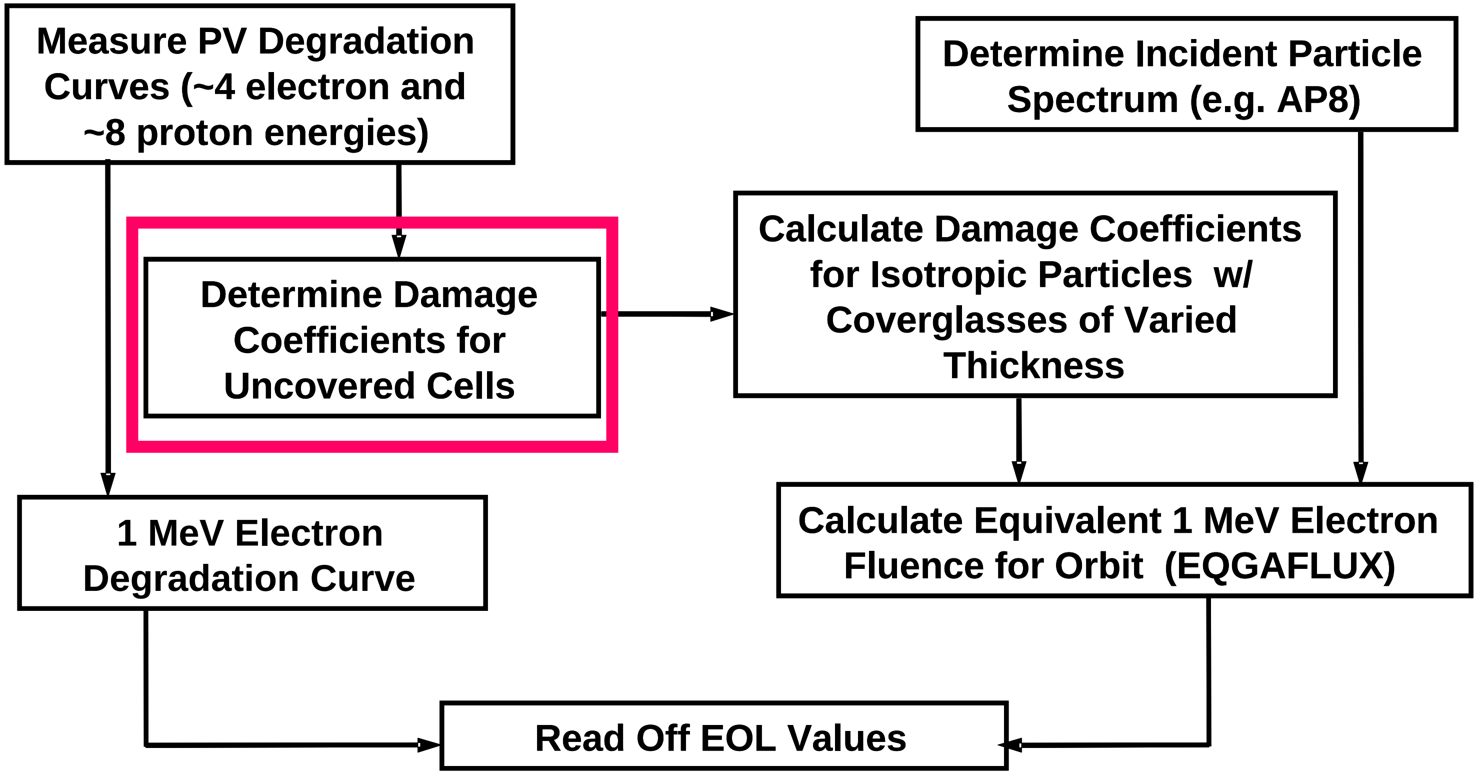


1MeV electron reference curve

We define an 'equivalent fluence' for a mission

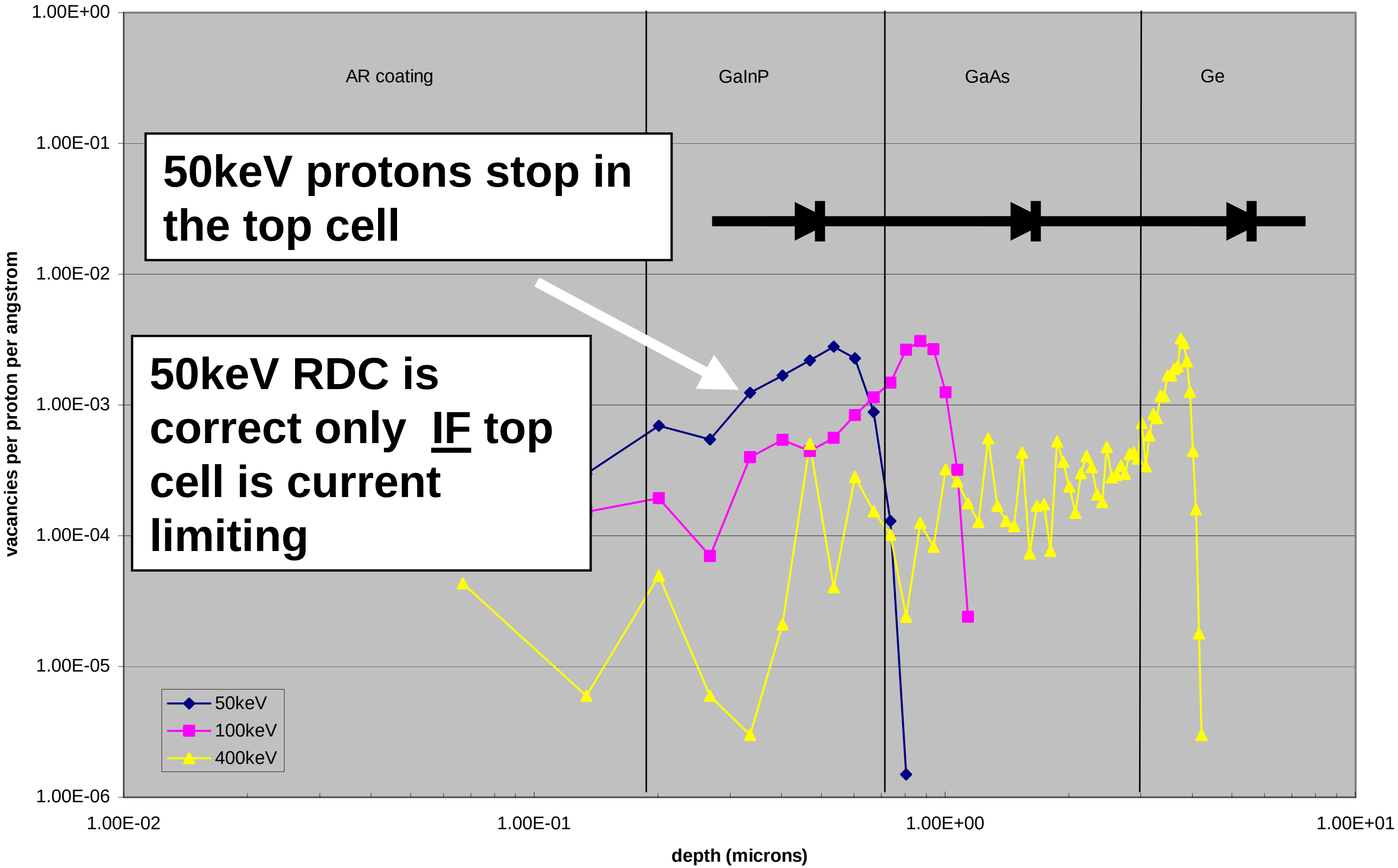
- *From S.R.Messenger et al, Progress in Photovoltaics 9, 103 (2001)*

JPL Equivalent Fluence Method

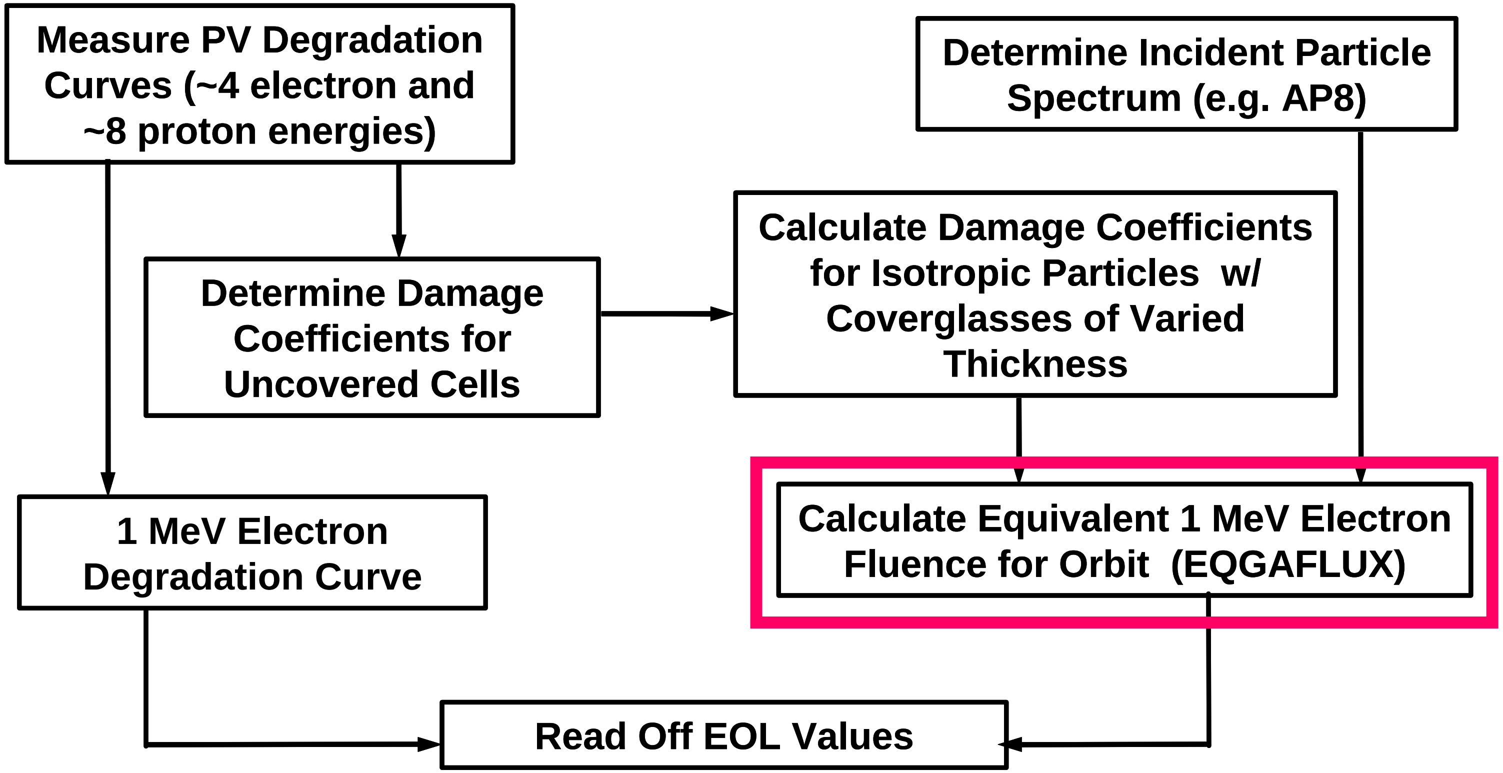


- *From S.R.Messenger et al, Progress in Photovoltaics 9, 103 (2001)*

Difficulties with application to Multi-Junction Cells – Example 1.

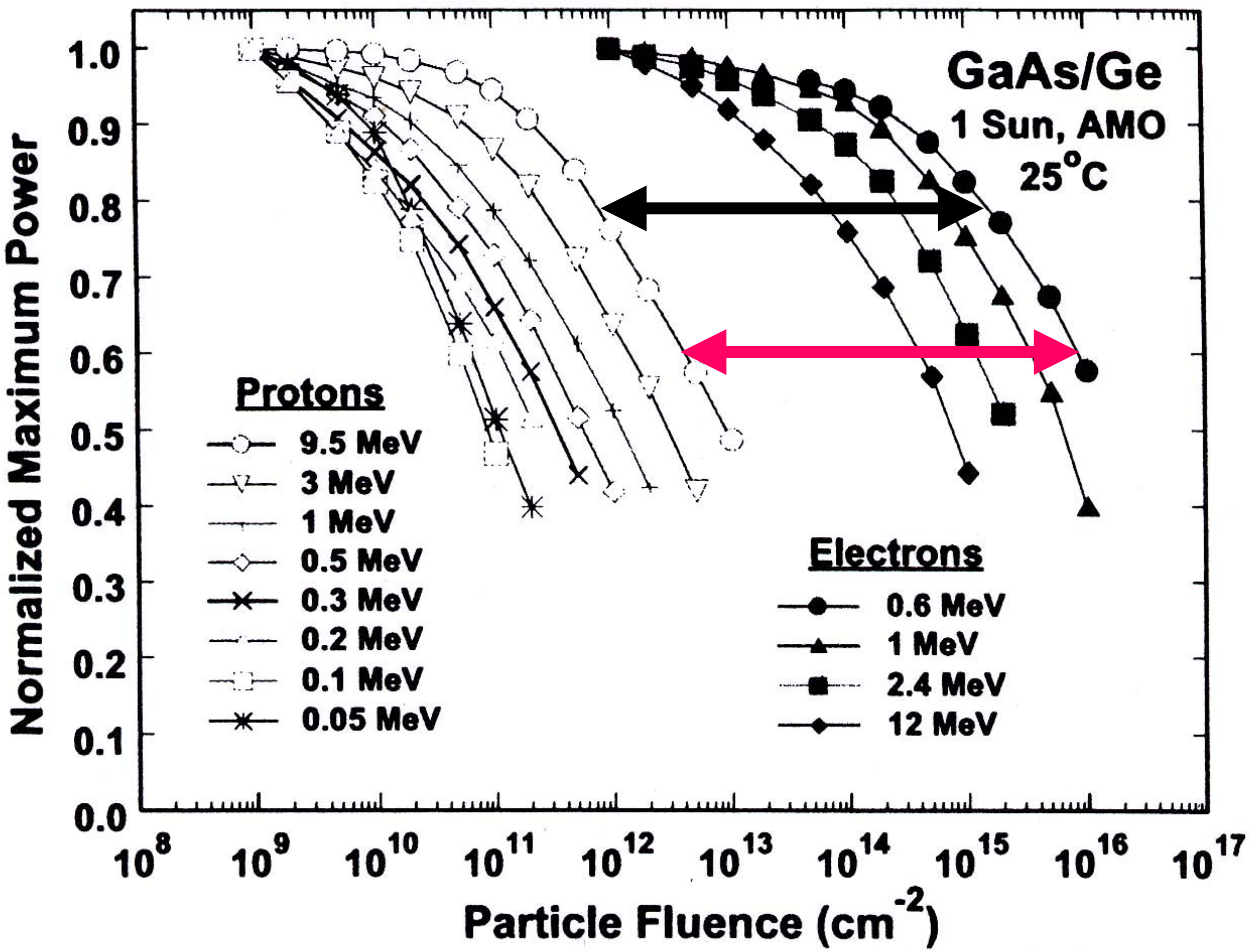


JPL Equivalent Fluence Method



- *From S.R.Messenger et al, Progress in Photovoltaics 9, 103 (2001)*

Establishment of Relative Damage Coefficients



RDC's are defined for a given remaining factor

All curves need to be parallel to give accurate results

Care needs to be taken for:

1. Triple-junction cells
2. Low energy protons

- *From S.R.Messenger et al, Progress in Photovoltaics 9, 103 (2001)*

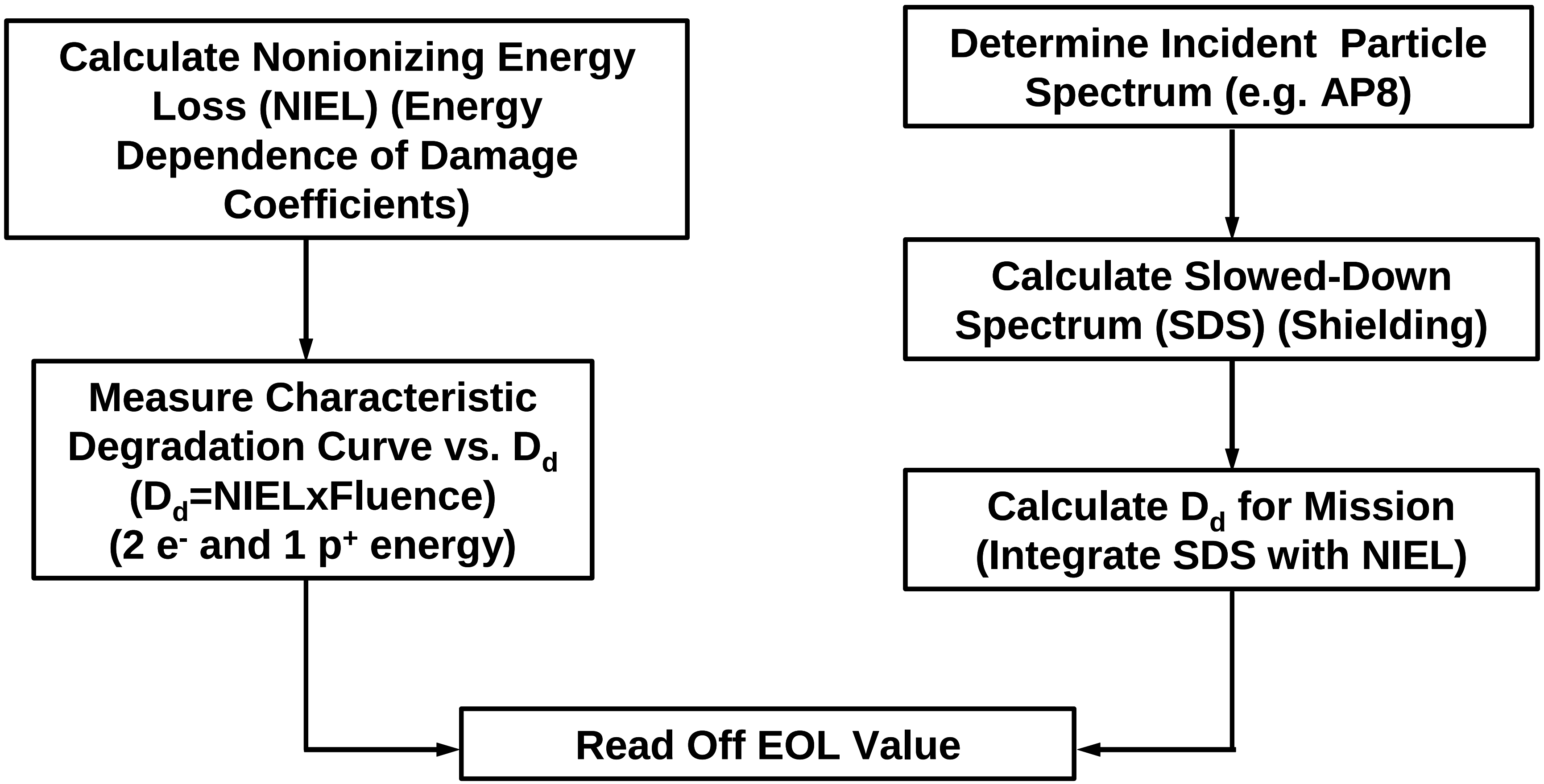
Array level considerations

- **Cells are electrically connected in series strings**
  - ***How uniform is cell degradation and how does this affect the string performance ?***
- **Array level testing – calibration uncertainties**
- **How accurate are corrections for albedo, temperature, incidence angle etc ?**
- **How do we combine all this information in a model of the power system ?**
- **What telemetry data is available ?**

- ***There are few available published comparisons between cell, ground level array testing and flight data for triple junction cells***

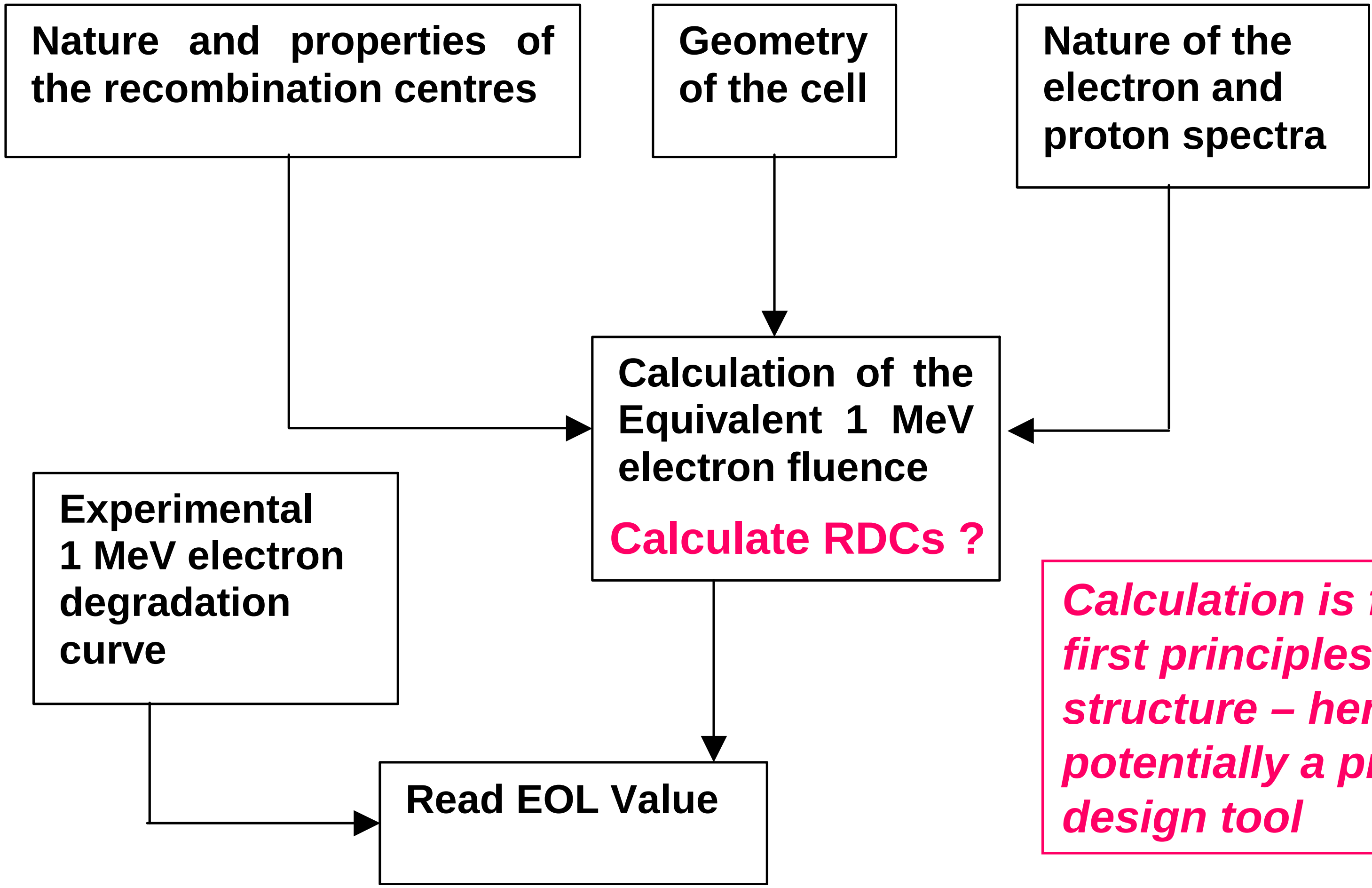
NRL Displacement Damage Dose Method

Potentially similar accuracy to EQFLUX from <u>less ground test data</u>



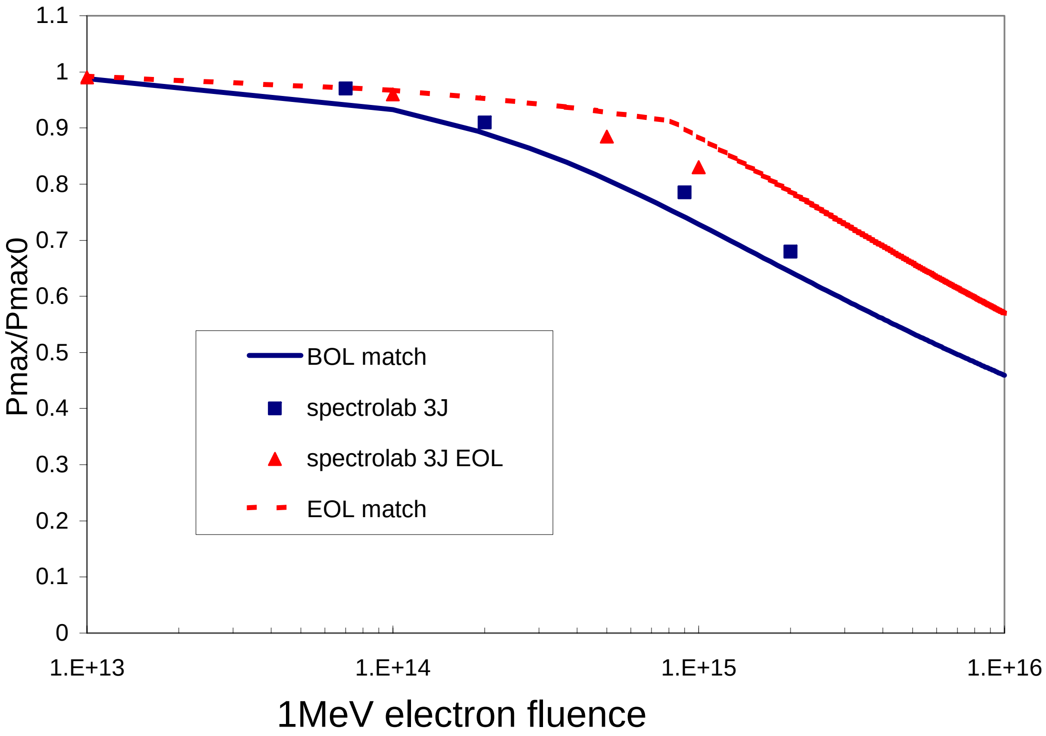
- *From S.R.Messenger et al, Progress in Photovoltaics 9, 103 (2001)*

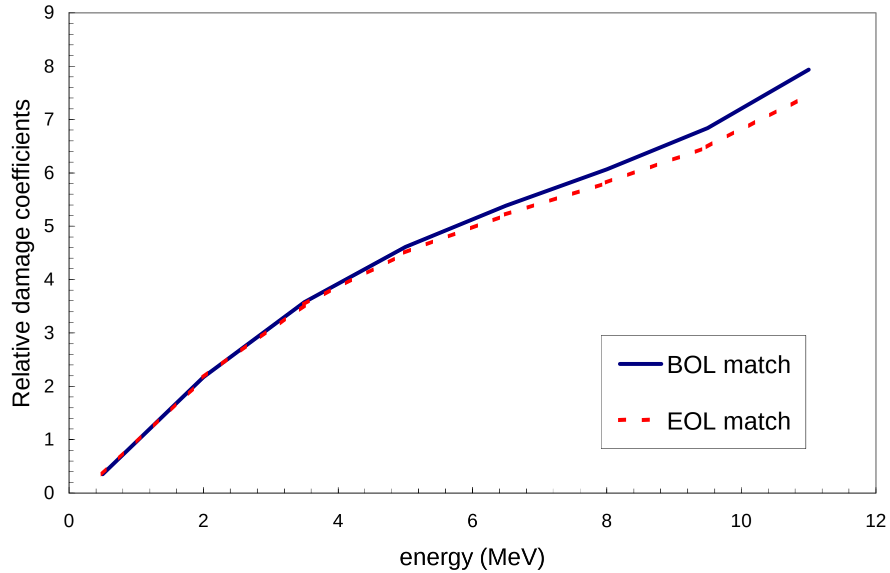
Fundamental Model – may be complementary to EQFLUX ?



Calculation is from first principles for any structure – hence potentially a predictive design tool

Preliminary results generated using 'MATHCAD' implementation





From N. de Angelis et al., Proc. IEEE PV specialists conf., 2005

Requirements for solar cell models in SPENVIS

- **EQFLUX is the 'default' reference**
  - ***We need to show that any new model can achieve at least an equivalent level of accuracy to EQFLUX***
  - ***We need to update the solar cell databases in EQFLUX both to use it accurately and to facilitate comparison***
- **Comparison with EQFLUX must be easy**
- **Validation is a critical step but published flight data for multi-junction cells is scarce**
- **Making SPENVIS an efficient forum for these models helps to facilitate validation / comparison and reduce duplication of effort within the community**

What to discuss at this workshop ?

- What does the community want from SPENVIS for solar array calculations ?
  - Updated RDC's for new cells ?
  - Implementation of NIEL based model ?
  - This will help us to focus resources effectively
- How to validate a new model ?
- How to apply a fundamental model ?
  - Calculate and upload RDC's into EQFLUX ?
  - A design tool complementary to EQFLUX or a completely new application ?
  - How to deal with confidentiality issues concerning cell structure ?