



Validating a new solar cell performance prediction tool for space applications against ground tests

Activity performed under contract ARTES AT 4F.126
ESA AO/1-9732/19/NL/NR



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Content

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II. What is the SADC tool?

III. Ground testing. Design and results.

IV. SADC application case within the OMERE freeware

I. About the ARTES project

The goal is to provide a precise and fast way to predict solar cell degradation due to space exposure.



Prime Contractor

Solar Array Degradation Calculator (SADC) development, validation, integration in publicly available tools & solar cell high energy radiation testing



Radiation environment modelling & solar cell radiation testing



Sensitivity analysis of degradation prediction & solar cell assemblies
Definition of industrial applications and constraints, end-user perspective and requirements specification



Definition of industrial applications and constraints, end-user perspective and requirements specification



Definition of industrial applications and constraints, end-user perspective and requirements specification

I. About the ARTES project

Interested in this project?

Full documentation & associated papers references



<https://connectivity.esa.int/projects/eor-environment-and-sadc-tool>

Online search keywords: **ESA artes solar cell SADC tool**

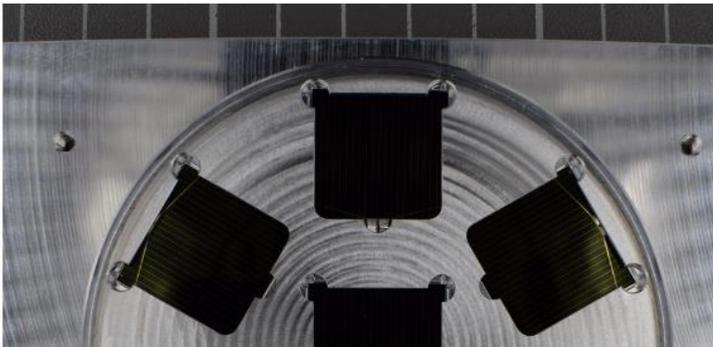
EOR environment and SADC tool Electric Orbit Raising Radiation Environment and Solar Array Degradation

Space Segment - Platform

Status: Completed Status date: 2023-07-17 Activity Code: 4#126

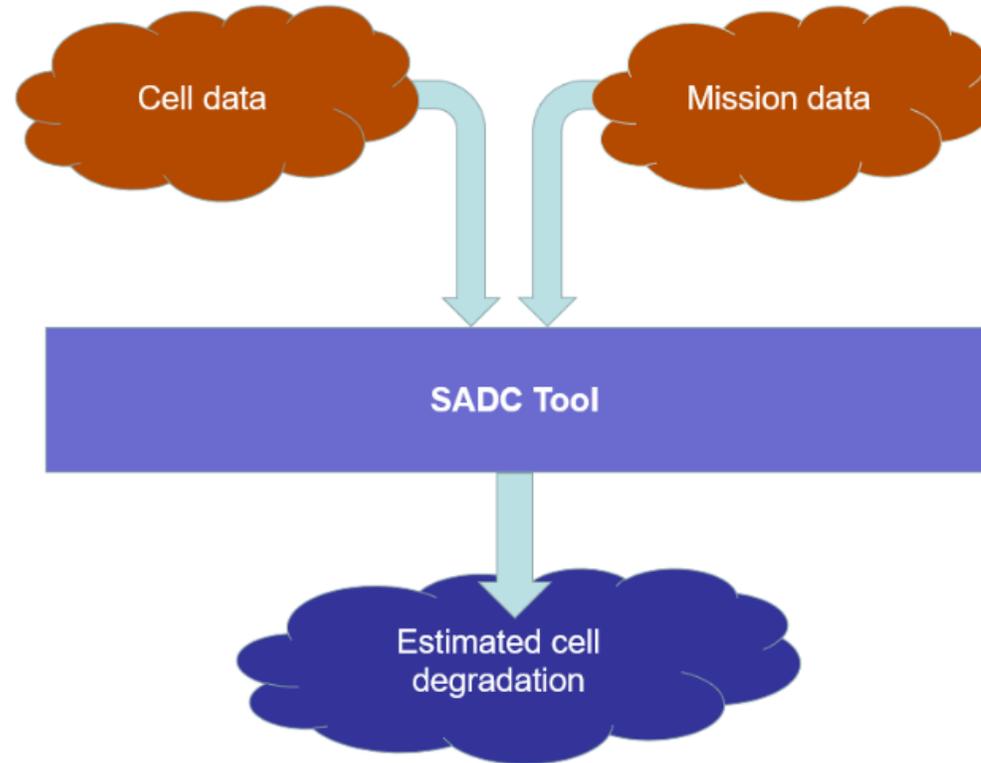
Objectives

The project objective is to provide a user friendly and fast way to predict solar cell degradation due to space exposure. In particular, the provided tool is validated against ground tests. The ground tests are designed specifically to assess core assumptions of the models used in the project. The end result is provided as both a standalone tool as well as integrated in the ESA Network of Models (nom.esa.int). An error of 2% is expected on the results.



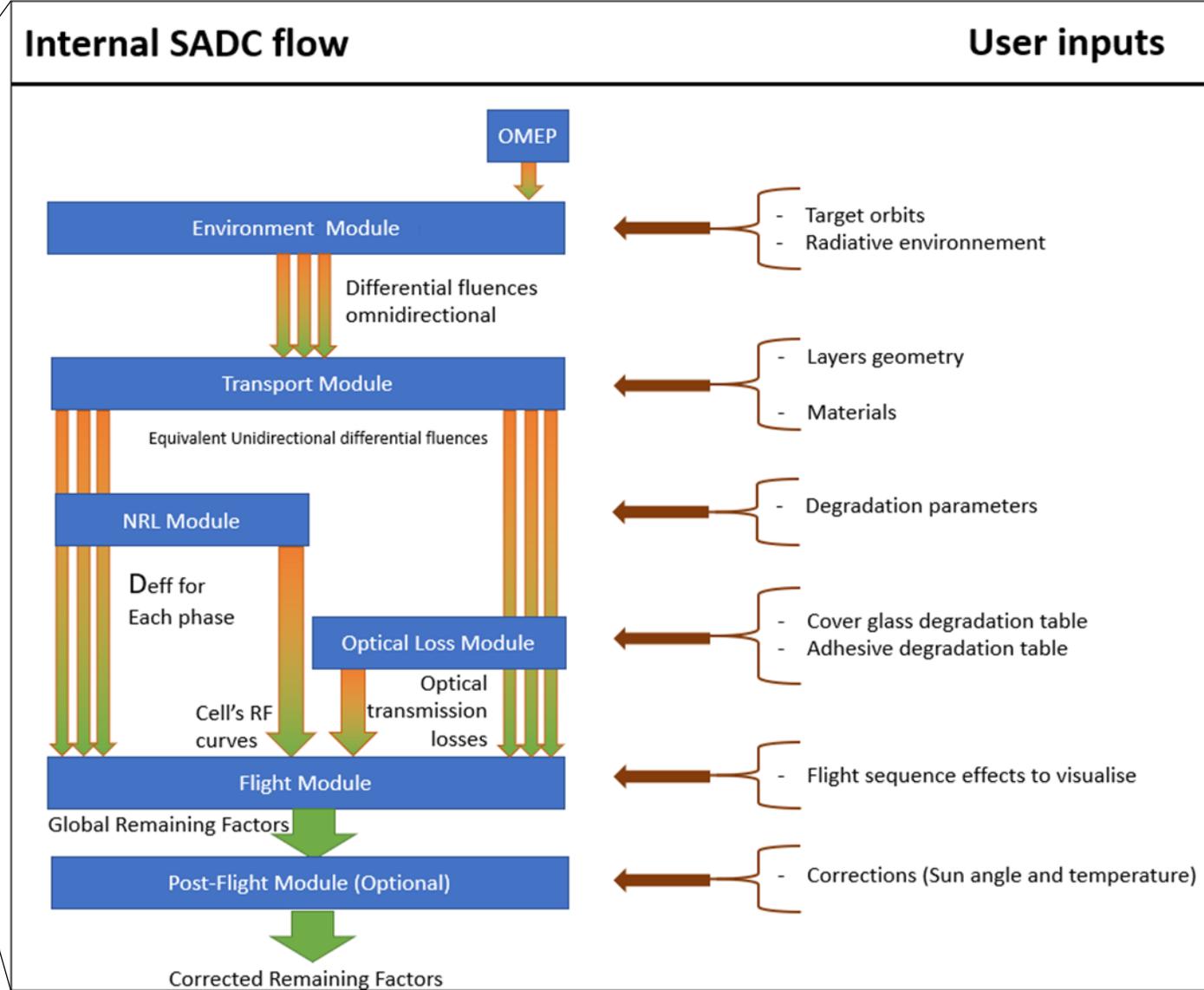
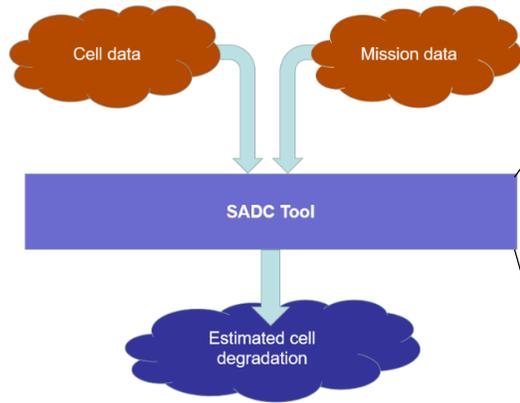
The SADC tool in a few words

Ground tests -
Past publications -
Expected design -
...Flight data -

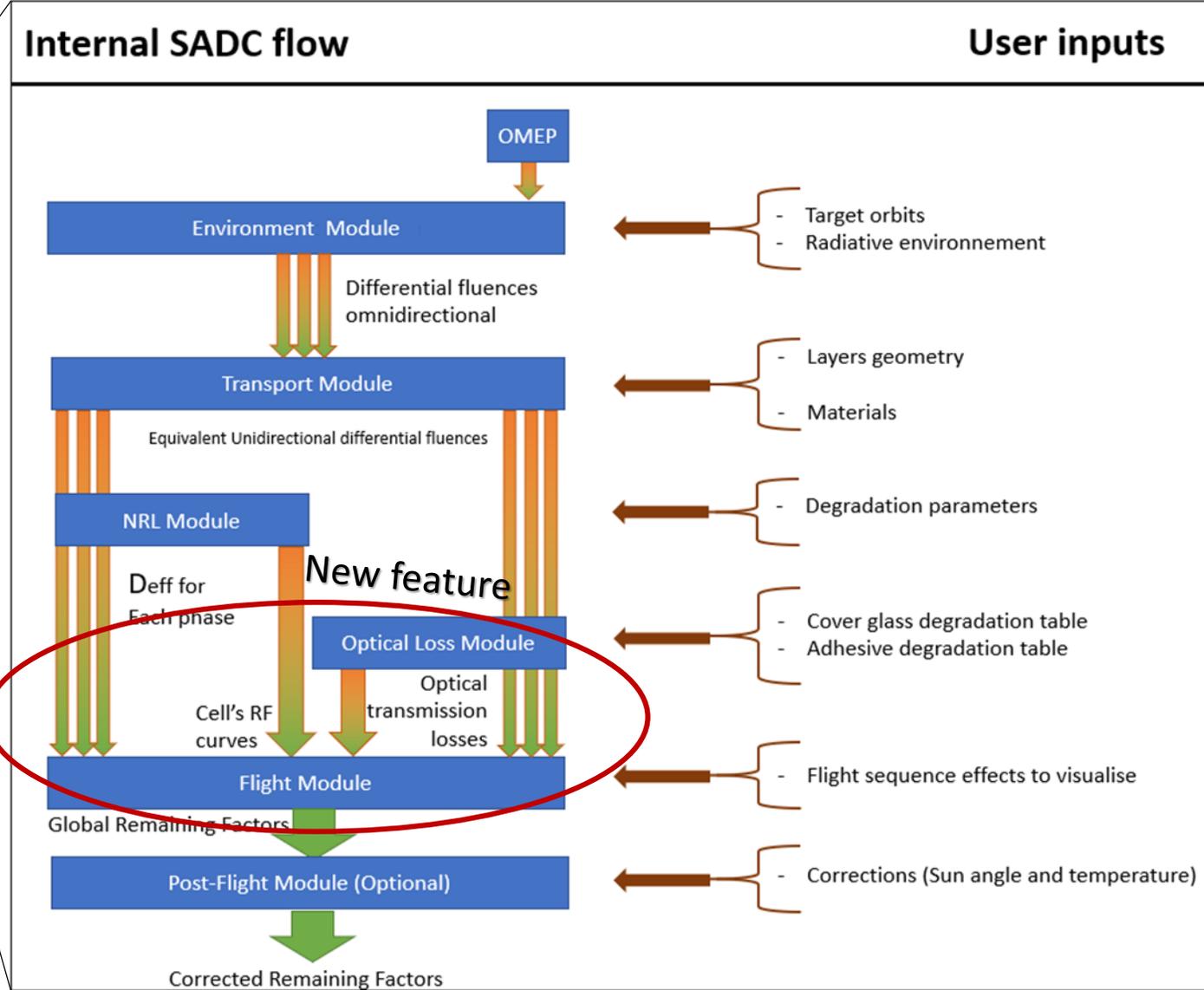
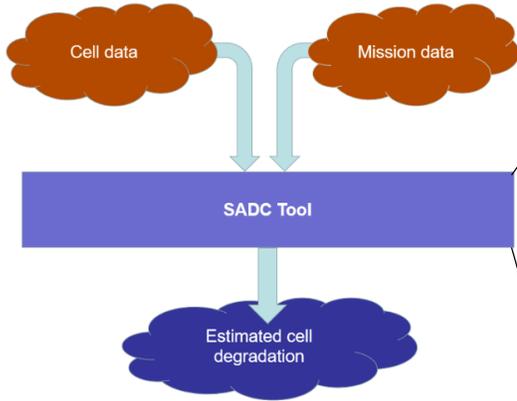


- Mission
- Environments Models
- Confidence levels...

The SADC tool in a few words



The SADC tool in a few words



Ground matrix definition

What is to be tested?

Superposition principle

DDD principle

Geometric superpositions (cell's layers effects)

What beams to use?

Environment representative

Avoid sample activation if possible

Sample configuration			Beam configuration		
ID	Type	Irradiation side	Particle type	Energy (MeV)	Fluence (#/cm ²)
DDD equivalence / Shielding effects					
ID1	8x BSC	Front	Protons	6	2.3e12
ID2	8x BSC	Rear	Protons	6	8.7e11
ID4	8x SCA	Front	Electrons	1	2.1e15
ID5	8x SCA	Rear	Electrons	1	2.1e15
ID9	8x BSC	Front	Electrons	1	2.1e15
Optical loss damage / Shielding effects					
ID6	8x SCA	Front	Protons	0.045	2.0e14
ID8	8x CVG		Protons	7.2	2.3e12
DDD equivalence / Combined particle conditions					
ID13	8x BSC	Front	Electrons	1	1.05e15
ID14			Protons	1.8	3.84e11
ID11	8x BSC	Front	Protons	1.8	3.84e11
ID12			Protons	6	1.15e12
ID15	8x BSC	Front	Electrons	1	1.05e15
ID10			Electrons	3	3.1e14

All test conditions aim for the same Isc damage.

Ground matrix definition

What is to be tested?

Superposition principle

DDD principle

Geometric superpositions (cell's layers effects)

What beams to use?

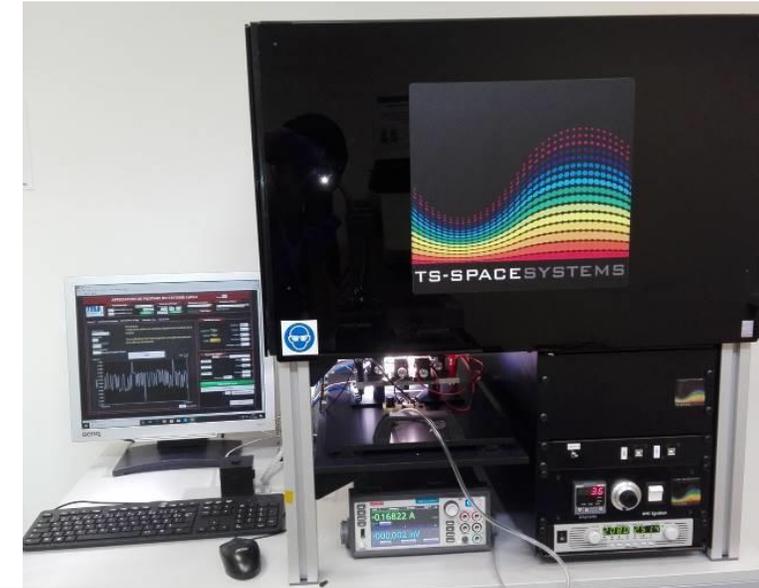
Environment representative

Avoid sample activation if possible

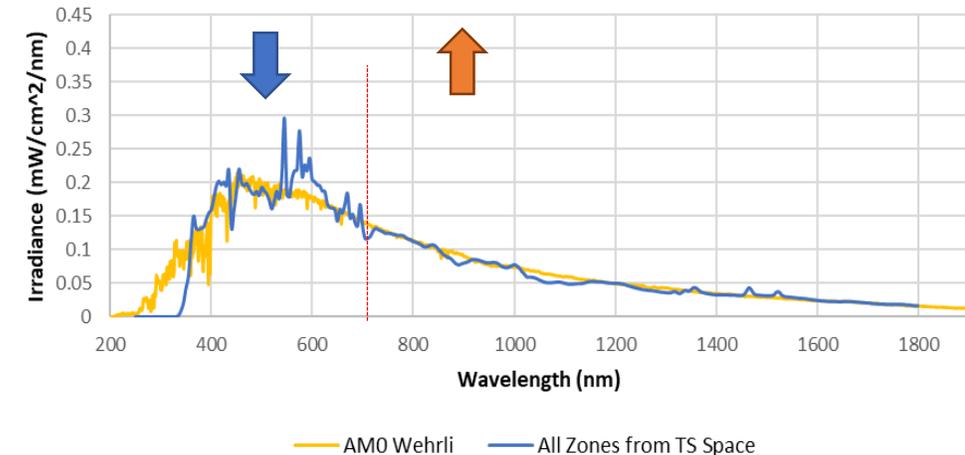
How to test the cells ?

Anneal the cells as per ECSS

Use multi zone sun simulators*

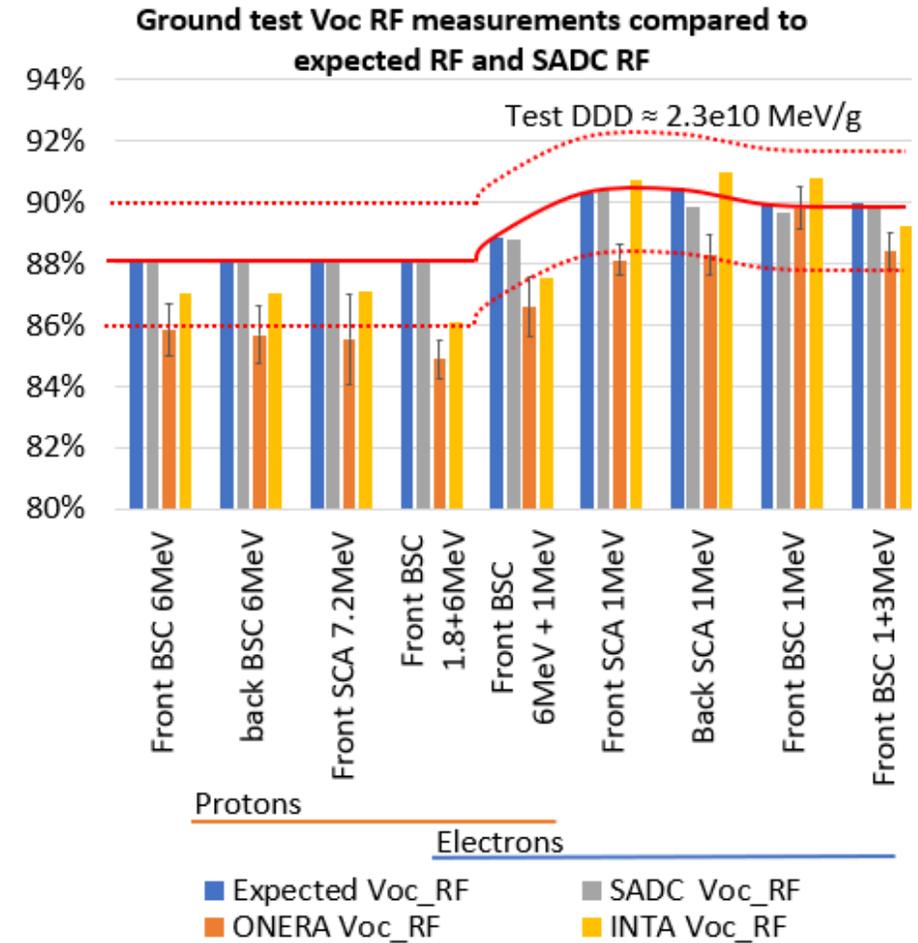
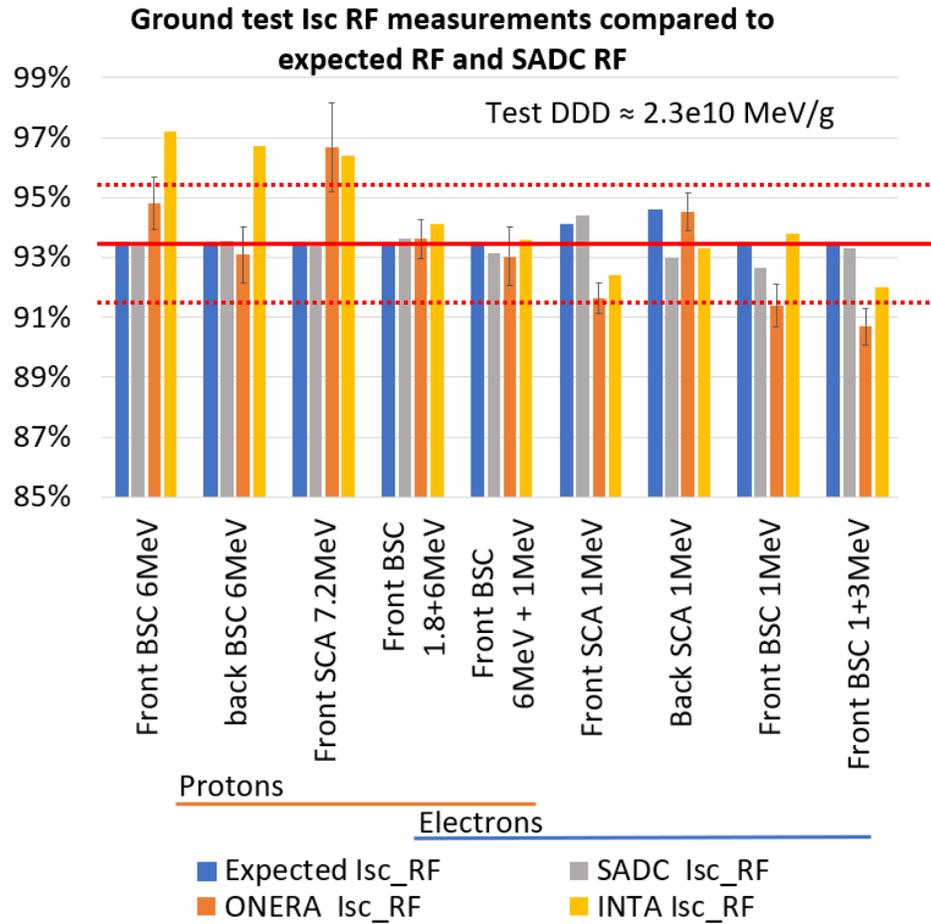


TRAD - Unisim Compact - Spectrum and AM0 Reference



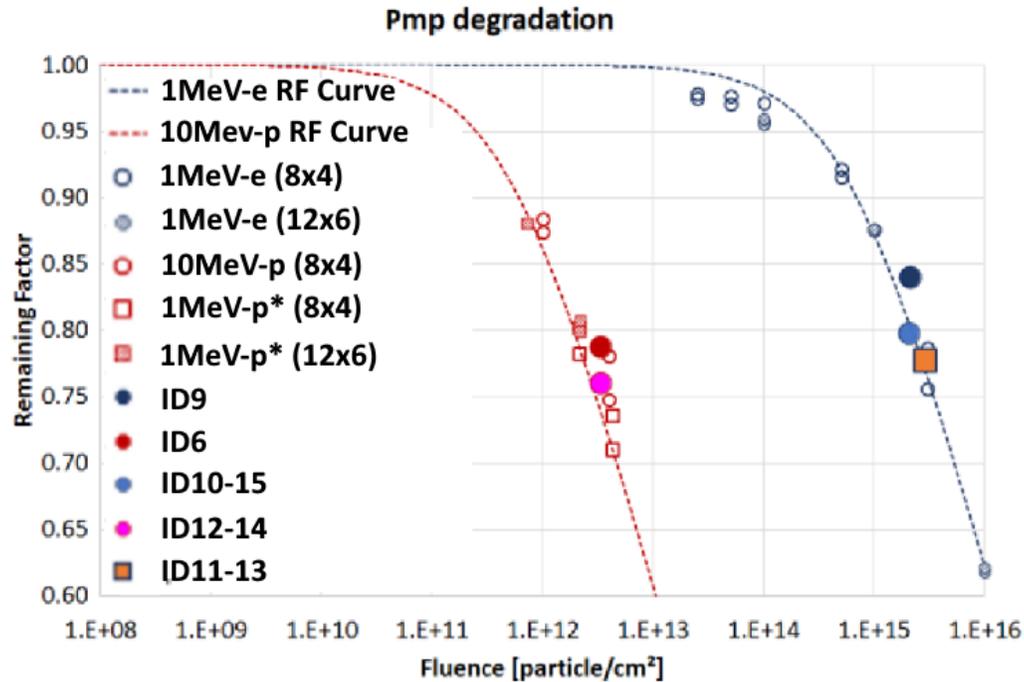
Test results

Ground tests vs SADC



Test results

Bare Solar Cells. Ground tests vs Legacy



INTA (Instituto Nacional de Técnica Aeroespacial)

Solar Cell Assemblies. SADC vs FASTRAD (TID)

		Front	Front	Front	Back
		p ⁺ 7.2MeV only	p ⁺ 7.2MeV+ 45keV (ID6+8)	e ⁻ 1MeV (ID4)	e ⁻ 1MeV (ID5)
Values as relative errors					
Coverglass	SADC vs FASTRAD FMC beam	0.04%	-32.23%	-10.9%	-55.6%
	SADC vs FASTRAD FMC omni	-2.52%	7.43%	0.62%	19.6%
Adhesive	SADC vs FASTRAD FMC beam	2.08%	2.08%	-29.2%	-38.0%
	SADC vs FASTRAD FMC omni	2.50%	2.50%	-17.5%	15.6%

The RF curve is derived from a cloud of data.
3G30 datasets dispersion is to be accounted for.



The SADC – command line interface and GUIs

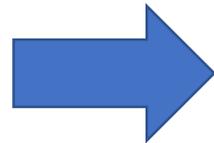
The standalone tool can be used as is...

```

===== 100 %
"lnP" (layer #1)
-----
Type           : optical
Thickness      : 1.0e+00 um
Density        : 4.810
Composition    : lnP
Incoming
* e- integ fluence : 2.310001e+15 cm^-2 [-5.00%,+5.00]
* Emin/Max        : 1.00e-02 MeV/8.00e+00 MeV
* front           : 2.310001e+15 cm^-2 [-5.00%,+5.00]
* back            : 0.000000e+00 cm^-2
* p+ integ fluence : 0.000000e+00 cm^-2
* Emin/Max        : 0.00e+00 MeV/0.00e+00 MeV
* front           : 0.000000e+00 cm^-2
* back            : 0.000000e+00 cm^-2
* light [ 200-200nm] : 100.000000 [-0.00%,+0.00]
Absorbed Dose
* e-             : 7.085435e+07 rad [-0.00%,+0.00%]
* front          : 7.085435e+07 rad [-0.00%,+0.00%]
* back           : 0.000000e+00 rad
* p+             : 0.000000e+00 rad
Transmission
* On GaAs band  : 100.000000 [-0.00%,+0.00]
Transmission    : 99.992151 [-0.00%,+0.00]

"GaAs" (layer #2)
-----
Type           : active
Thickness      : 2.0e+00 um
Density        : 5.120
Composition    : GaAs
Incoming
* e- integ fluence : 2.032309e+15 cm^-2 [-0.00%,+10.53]
* Emin/Max        : 1.00e-03 MeV/8.00e+00 MeV
* front           : 2.032309e+15 cm^-2 [-0.00%,+10.53]
* back            : 0.000000e+00 cm^-2
* p+ integ fluence : 0.000000e+00 cm^-2
* Emin/Max        : 0.00e+00 MeV/0.00e+00 MeV
* front           : 0.000000e+00 cm^-2
* back            : 0.000000e+00 cm^-2
* light [ 750-0900nm] : 100.000000 [-0.00%,+0.00]
Isc
* e- Displacement(p+ Eq) : 2.766725e+10 g^-1 MeV [-53.96%,+143.58%]
* p+ Displacement        : 0.000000e+00 g^-1 MeV
* Remaining factor       : 92.32% [-11.46%,+4.67%]
* Global rem. factor     : 92.32% [-11.46%,+4.67%]
Voc
* e- Displacement(p+ Eq) : 1.277429e+10 g^-1 MeV [-63.93%,+261.61%]
* p+ Displacement        : 0.000000e+00 g^-1 MeV
* Remaining factor       : 89.55% [-4.50%,+3.36%]
Pmax
* e- Displacement(p+ Eq) : 1.494526e+10 g^-1 MeV [-56.67%,+180.60%]
* p+ Displacement        : 0.000000e+00 g^-1 MeV
* Remaining factor       : 78.30% [-18.22%,+11.70%]
* Global rem. factor     : 78.30% [-18.22%,+11.70%]
Ipm
* e- Displacement(p+ Eq) : 2.766725e+10 g^-1 MeV [-54.17%,+147.40%]
* p+ Displacement        : 0.000000e+00 g^-1 MeV
* Remaining factor       : 89.63% [-14.16%,+6.31%]
* Global rem. factor     : 89.63% [-14.16%,+6.31%]

```



... But a GUI is more userfriendly

The GUI displays a 3D visualization of trapped electrons around Earth, titled "Trapped electrons AE8 max - JENSEN_CAIN - 1.0000 MeV". The visualization shows a globe with a complex network of colored lines representing electron trajectories. A color scale on the right indicates flux levels from 1.06e+00 to 1.13e+05 cm²/s.

The "Solar Cell Degradation" window is open, showing the following configuration:

- Flux: From mission data
- Degradation Model: SADC
- SADC Specific:
 - Layer list:
 - Optical Layer - coverglass: Type: Optical Layer
 - Optical Layer - cg_adhesive: Type: Optical Layer
 - Optical Layer - lnP: Type: Optical Layer
 - Active Layer - GaAs: Type: Active Layer
 - Active Layer Parameters:
 - Layer name: GaAs
 - Family: Semiconductors
 - Thickness: 2
 - Unit: um
 - Density: 5.12 g/cm³
 - Formula: GaAs
 - Spectral response min: 750 nm
 - Spectral response max: 900 nm
 - Electron niel type: GaAs
 - Proton niel type: GaAs
- Output: C:\Users\soufan.yijou\Documents\OMERE 5.7\solarcells.dat
- Calculations: Calculation + Graph, Calculation, Ok, Cancel



The SADC – command line interface and GUIs

TID sensitive (darkening)

TNID sensitive (NRL model)



Solar Cell Degradation

Flux
Type: From mission data

Degradation Model
SADC

SADC Specific

Layer list

→ Optical Layer - coverglass	+	×	−	↑	↓
→ Optical Layer - cg_adhesive	−	−	−	↑	↓
→ Optical Layer - InP	−	−	−	↑	↓
→ Active Layer - GaAs	−	−	−	↑	↓
→ Shielding Layer - Ge	−	−	−	↑	↓
→ Shielding Layer - BackContact	−	−	−	↑	↓
→ Shielding Layer - back_adhesive	−	−	−	↑	↓
→ Shielding Layer - Aluminium back plate	−	−	−	↑	↓



Active layer specific inputs

Active Layer - GaAs

Type: Active Layer

Active Layer Parameters

Layer name: GaAs

Family: Semiconductors

Thickness: 2

Unit: μm Density: 5.12 g/cm^3

Formula: GaAs

Spectral response min: 750 nm

Spectral response max: 900 nm

Electron niel type: GaAs

Proton niel type: GaAs

Electrical parameters

Isc

Electrical Name	Isc		
Electrical Type	ISC		
Ne	1	Error:	0 %
Np	1	Error:	0 %
Ce	0.948	Error:	0 %
Cp	0.948	Error:	0 %

Optical layer specific inputs

The screenshot displays the SADC GUI for configuring an optical layer. The interface is organized into sections with expandable/collapsible headers. The 'Optical Layer - coverglass' section is expanded, showing various parameters. The 'Optical Layer Parameters' section is also expanded, showing specific values for each parameter. The 'Transmission path' field is highlighted in pink, indicating it is the active field.

Parameter	Value
Type	Optical Layer
Layer name	coverglass
Family	Glass
Thickness	100
Unit	um
Density	2.61 g/cm ³
Formula	SiO ₂
Transmission path	...al loss\Optical_loss_table .dat
Transmission error	0 %

The SADC – command line interface and GUIs

```
# Result
#=====
# "coverglass" (layer #1)
#           Light
# Transmission min | Transmission max | Reaching layer ||
#           (nm)   |           (nm)   |           (%)  ||
#-----|-----|-----|
#           200     |           2000   |           100  ||

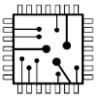
# "cg_adhesive" (layer #2)
#           Light
# Transmission min | Transmission max | Reaching layer ||
#           (nm)   |           (nm)   |           (%)  ||
#-----|-----|-----|
#           200     |           2000   |           91.6944 ||

# "InP" (layer #3)
#           Light
# Transmission min | Transmission max | Reaching layer ||
#           (nm)   |           (nm)   |           (%)  ||
#-----|-----|-----|
#           200     |           2000   |           91.6944 ||

# "GaAs" (layer #4)
#           Light
# Sensitivity min  | Sensitivity max  | Reaching layer ||
#           (nm)   |           (nm)   |           (%)  ||
#-----|-----|-----|
#           750     |           900    |           100  ||

# Electrical parameters
# Name            | DDDe            | DDDe->p        | DDDp            | RF              | GRF             ||
#                 | (MeV/g)         | (MeV/g)        | (MeV/g)         | (%)            | (%)            ||
#                 | min            | mid            | max            | min            | mid            | max            ||
#-----|-----|-----|-----|-----|-----|-----|
# Isc            | 2.1924e+10     | 2.1924e+10     | 2.09061e+09    | 93.2594        | 93.2594        | 93.2594        ||
# Voc            | 2.1924e+10     | 1.01226e+10    | 2.09061e+09    | 89.6626        | 89.6626        | 89.6626        ||
# Pmax           | 2.1924e+10     | 1.18429e+10    | 2.09061e+09    | 79.048         | 79.048         | 79.048         ||
# Ipm            | 2.1924e+10     | 2.1924e+10     | 2.09061e+09    | 90.8129        | 90.8129        | 90.8129        ||
# Vpm            | 2.1924e+10     | 4.3285e+09     | 2.09061e+09    | 89.3           | 89.3           | 89.3           ||
```





Conclusion

- A new degradation tool was developed around the NRL method and the coverglass optical losses
- The tool was validated against ground tests
- The beta version is available for user's feedbacks
 - In NoM (ESA)
 - In OMERE



Thank you for your attention

For further information on:

www.trad.fr – www.fastrad.net
www.rayxpert.com – www.r2cots.com



TRAD Tests & Radiations
@TRAD_Officiel



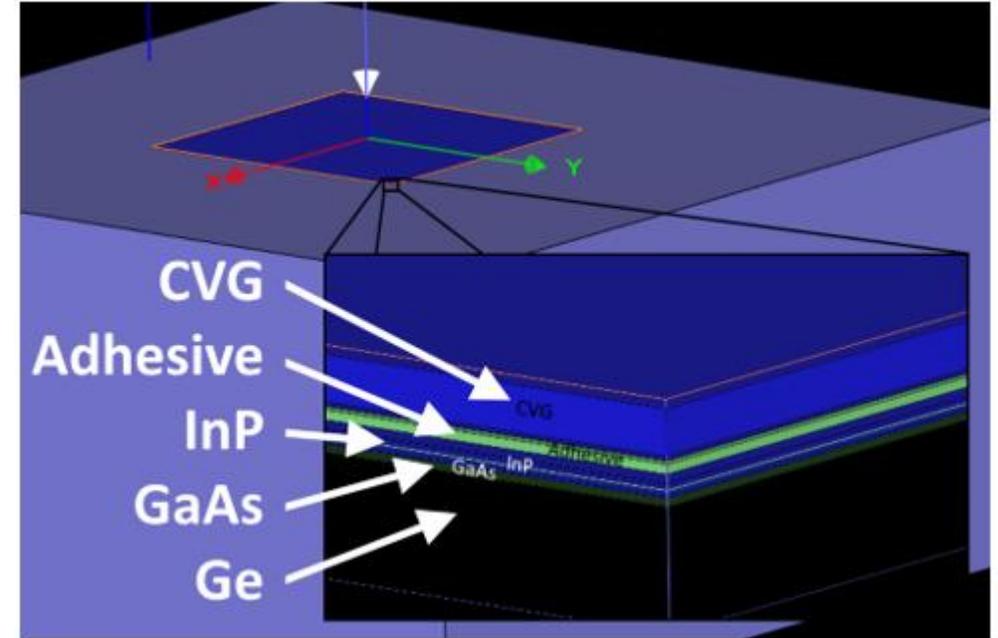
trad@trad.fr



+33 (0)5 61 00 95 60

The optical loss module, a first approximation

Main requirements	1st approximation within the SADC
Find a quantity to link the darkening with.	TID within the sensitive layer is computed and then converted into a transmission spectrum loss
Derive darkening from TID	Based on a look-up table (user defined for best results)
Dose profile management	Not available to the user. The tool is ready.
Effect on electrical performance	Based on wavelength bandwidth definitions
Effects on limiting subcell (if any)	Same as above + based on current matching design (user input)
UV, AO and other coverglass aging effects	Not available in the SADC v1.4BETA



Fastrad model of a solar cell assembly