Impact of IRENE models on Total Ionizing Dose, Single Event Effects and solar cell degradation, using OMERE and FASTRAD softwares

Damien HERRERA (TRAD), *Rémi Benacquista (TRAD), Kevin LEMIERE (TRAD),*
Soufian YJJOU (TRAD), Robert ECOFFET (CNES)

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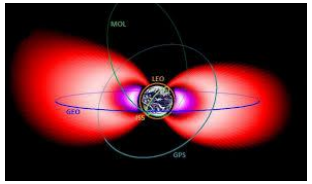


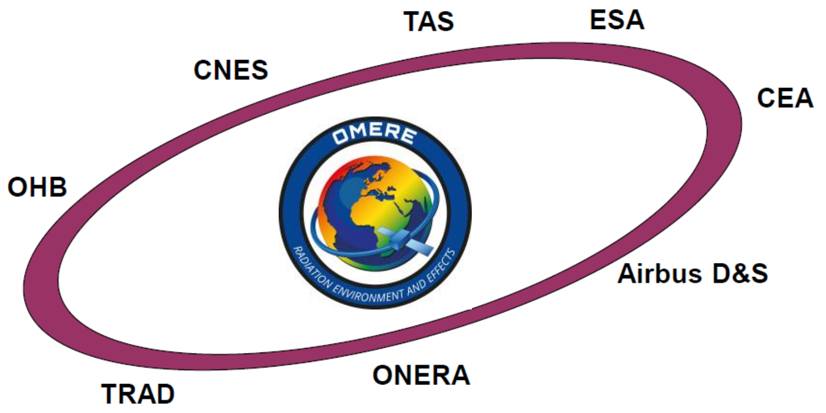
Overview

- OMERE software
- FASTRAD software
- Impact on Total Ionizing Dose (TID)
- Impact on Single Event Effect (SEE) rate calculation
- Impact on Solar cells degradation
- Conclusion

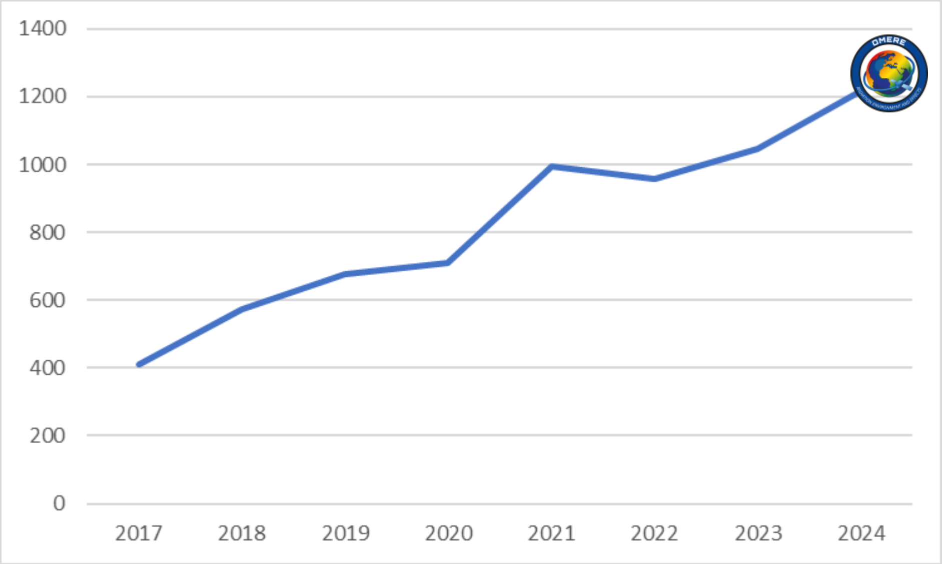
OMERE software

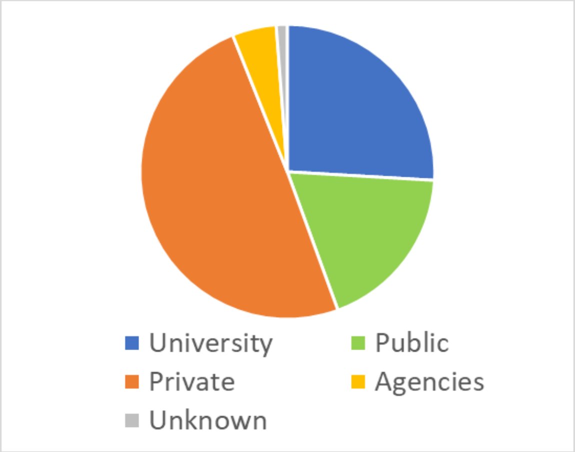
The OMERE software

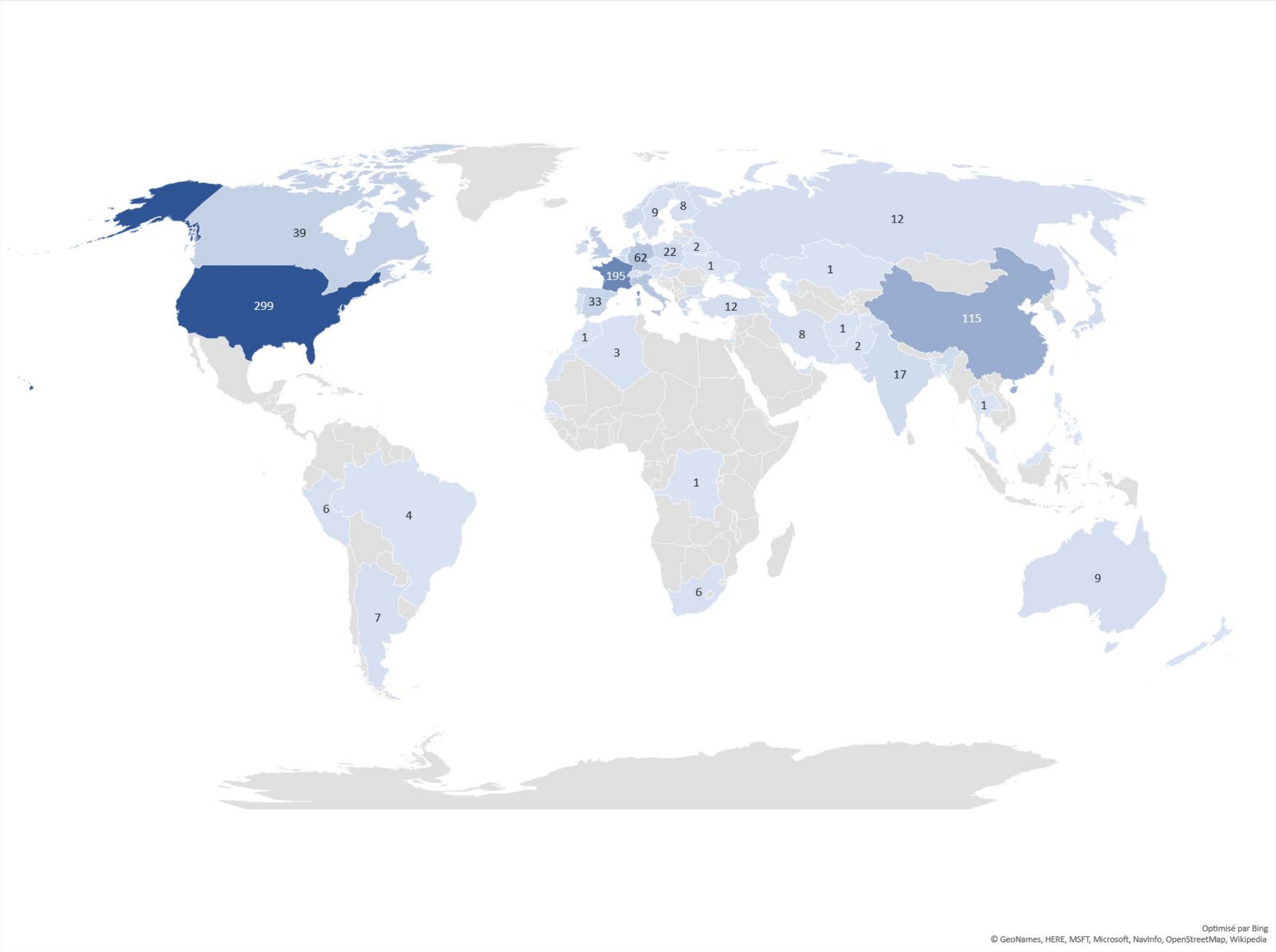
- The project
  - Since 1999
  - TRAD development with CNES support
  - Freeware for space radiation environment and effects on electronic components
  - Stand alone software (no internet connection needed)
  - Conceived to meet industrial requirements
  - Integrates ONERA models
  - Integrates outcomes of Research and Technology projects financed by CNES
  - Coupling with FASTRAD.



The OMERE software







The OMERE software

<u>Input : Mission</u>

- Compute orbit with OMERE
- File import

<u>Environment</u>

- Particle sources (trapped and solar particles, cosmic rays)
- ECSS and US standard models

Degradation due to Atomic Oxygen

Solar cell degradation (SADC)

SEE rate calculation

Dose depth curves (TID et TNID)

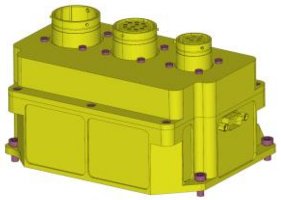
Inputs for FASTRAD

- Many other functionnalities
- User Manual

FASTRAD software

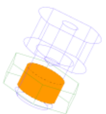
The FASTRAD® software

- Created in 2001
- +150 users worldwide
- 3D interface
- User Manual
- Mappings,
- Multithreading calculations, …



Input: Radiation model

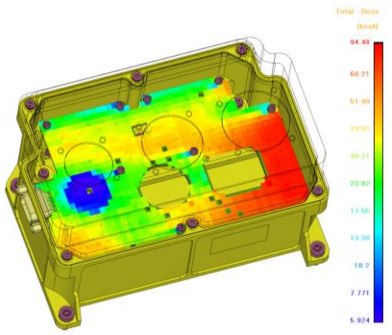
Modeling step
- Materials
- Components

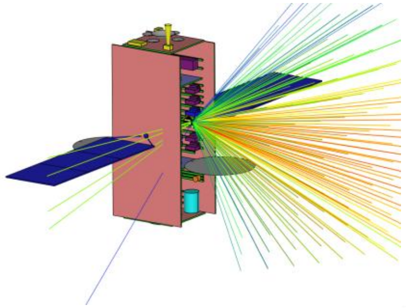


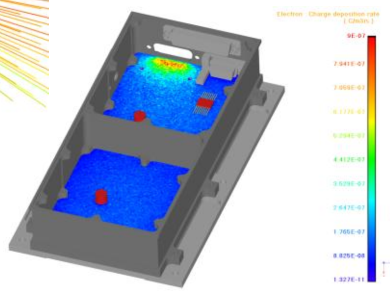
Space environment
OMERE / Other files

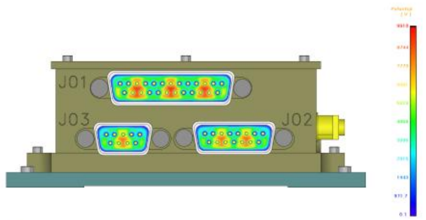
TID/TNID calculations

Internal charging calculations









Impact on Total Ionizing Dose (TID)

Missions and space environment models

- Four missions:
  - LEO: 800 km, 98°, 10 years
  - MEO GALILEO: 23222 km, 56°, 12 years
  - GEO: 15 years,
  - EOR (LEO 250 km to GEO): 130 days

Mission	Trapped electrons	Trapped protons
LEO, MEO and EOR	AE8 max	AP8 min
	AE9 mean	AP9 mean
	AE9 PM-mean	AP9 PM-mean
	AE9 PM-80/90/95%	AP9 PM-80/90/95%
GEO	All + IGE 2006	All

Methodology

OMERE

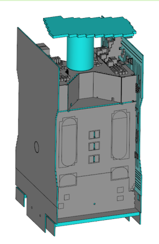
4 missions:
GEO, LEO, MEO, EOR

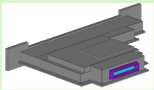
Space environment models:
Ax9, Ax8, IGE2006

Spectrum

Total Ionizing Dose-depth curve for each model

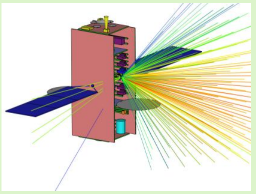
FASTRAD





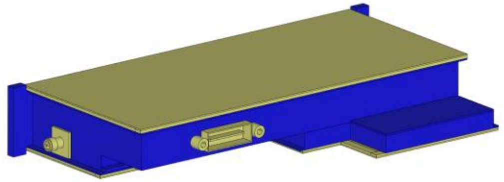
3D models

Dose at component level

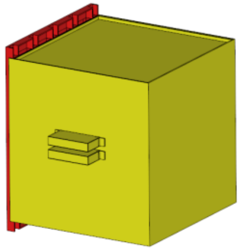


Dose ratio between IRENE and reference model

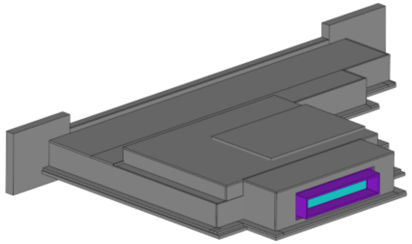
Models: Platforms, units and components



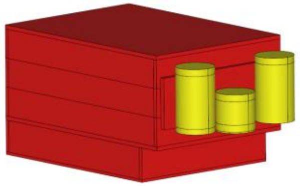
Unit A



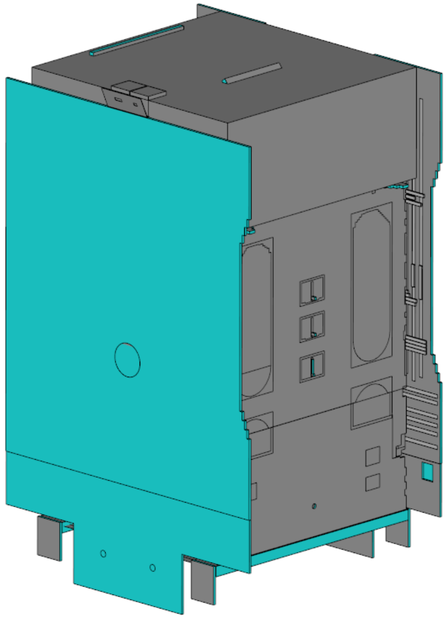
Unit B



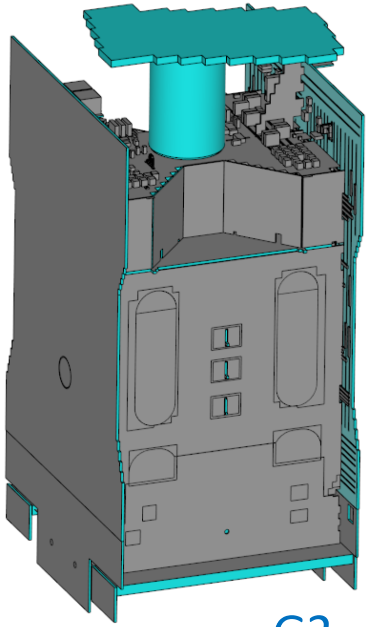
Unit C



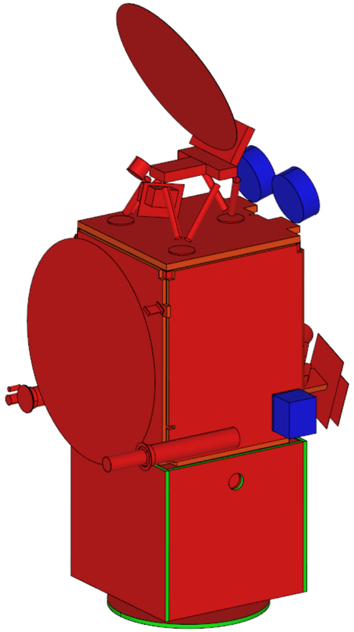
ICARE



G1



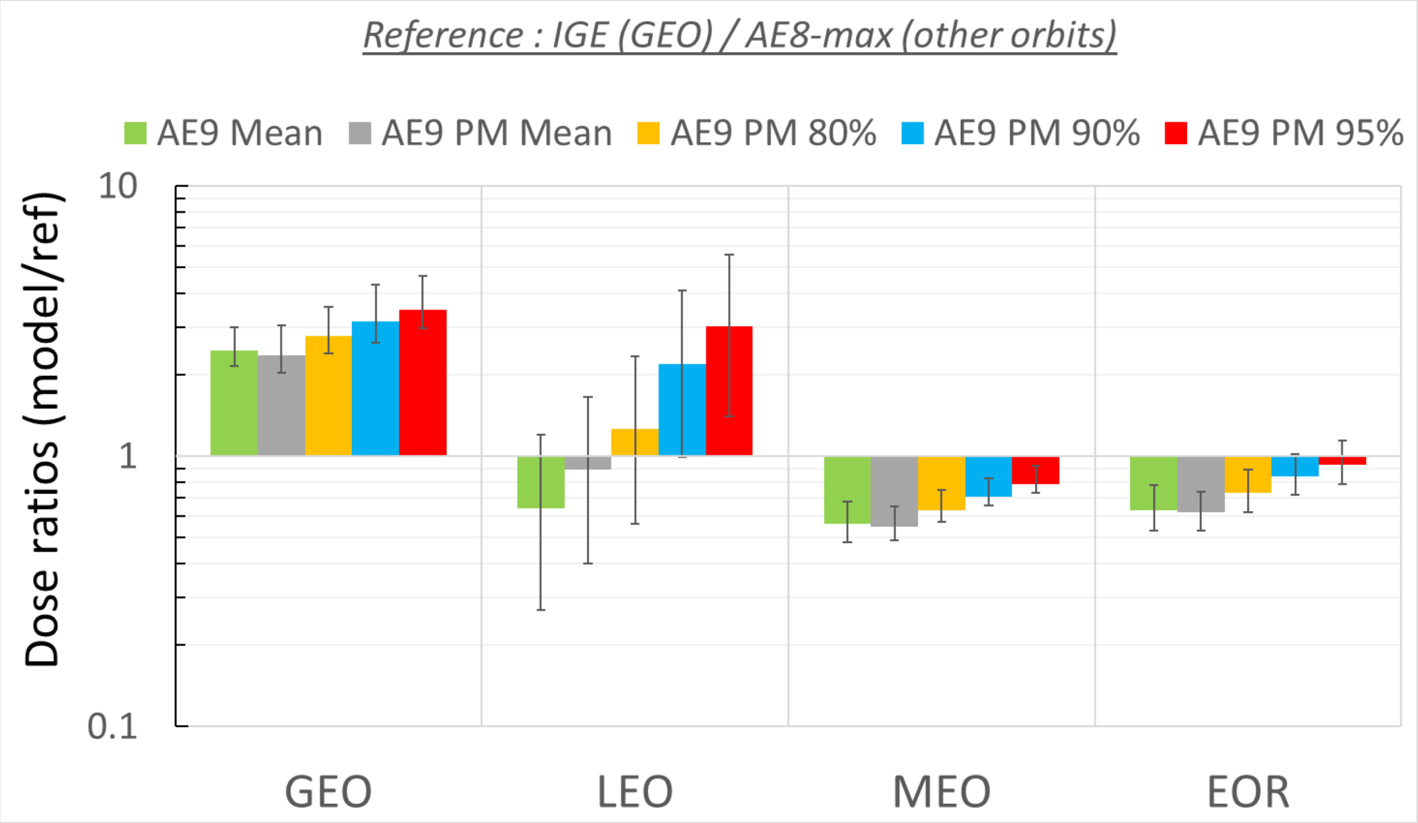
G2



JASON2

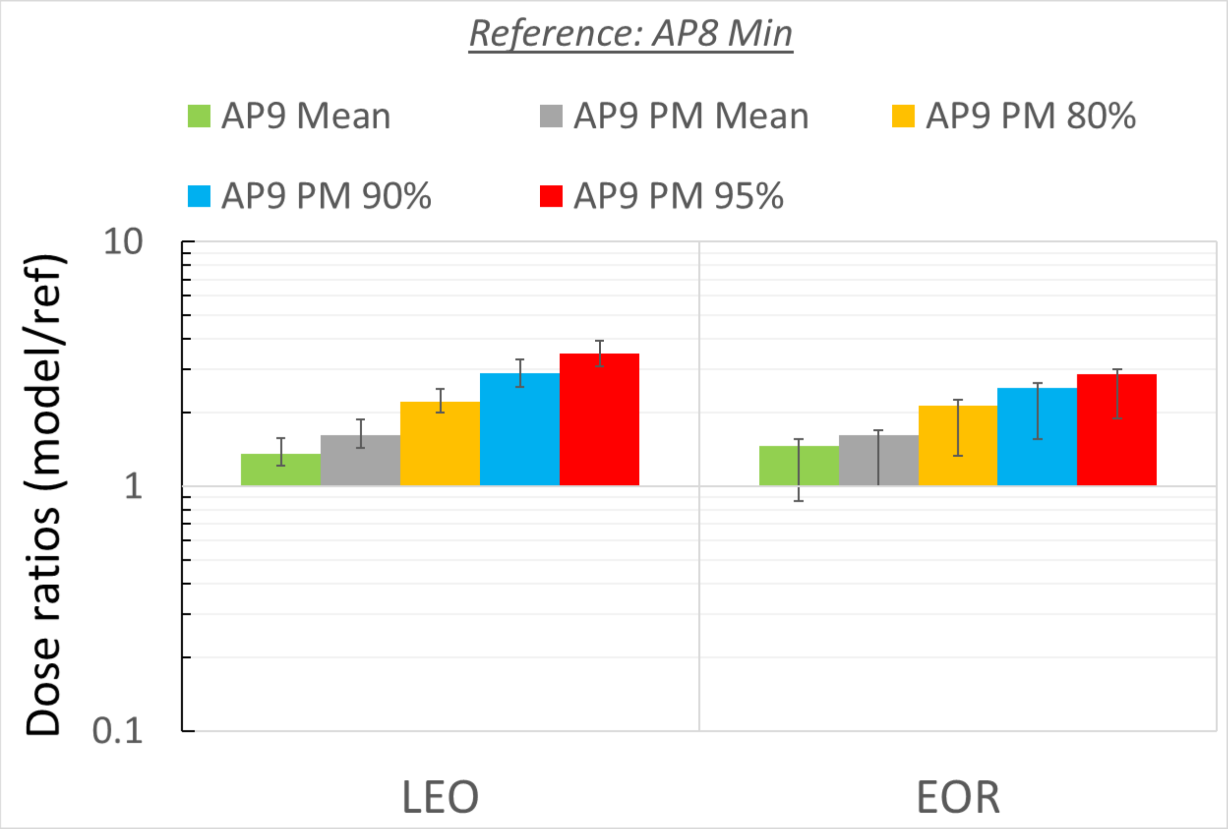
Models	Equipments	Detectors
G1_unitA	10	530
G1_unitB	10	730
G1_unitC	10	530
G2_unitA	10	530
G2_unitB	10	730
G2_unitC	10	530
JASON_ICARE	6	2262
Total		5842

Dose ratio for trapped electrons



- Ratios between 0.3 and 6.
- **EOR and MEO**: AE9 underestimates the dose compared to AE8, low range between min and max ratio → Same behavior for all the detectors,
- **GEO**: AE9 overestimates the dose compared to IGE2006 (from 2 to 5),
- **LEO**: Huge impact of percentile parameter. High range between min and max ratio → Hard to say if using AE9 will under or overestimate the dose.

Dose ratio for trapped protons



- Ratios between 1.2 and 4.
- **LEO and EOR**: AP9 overestimates the dose compared to AP8,
- The dose slightly increases with the percentile parameter,
- **LEO:** Low range between min and max ratios → Could be used for predictive behavior,
- **EOR:** Max ratios near the average value, meaning that only few detectors experiment a low dose level.

Impact on SEE rates

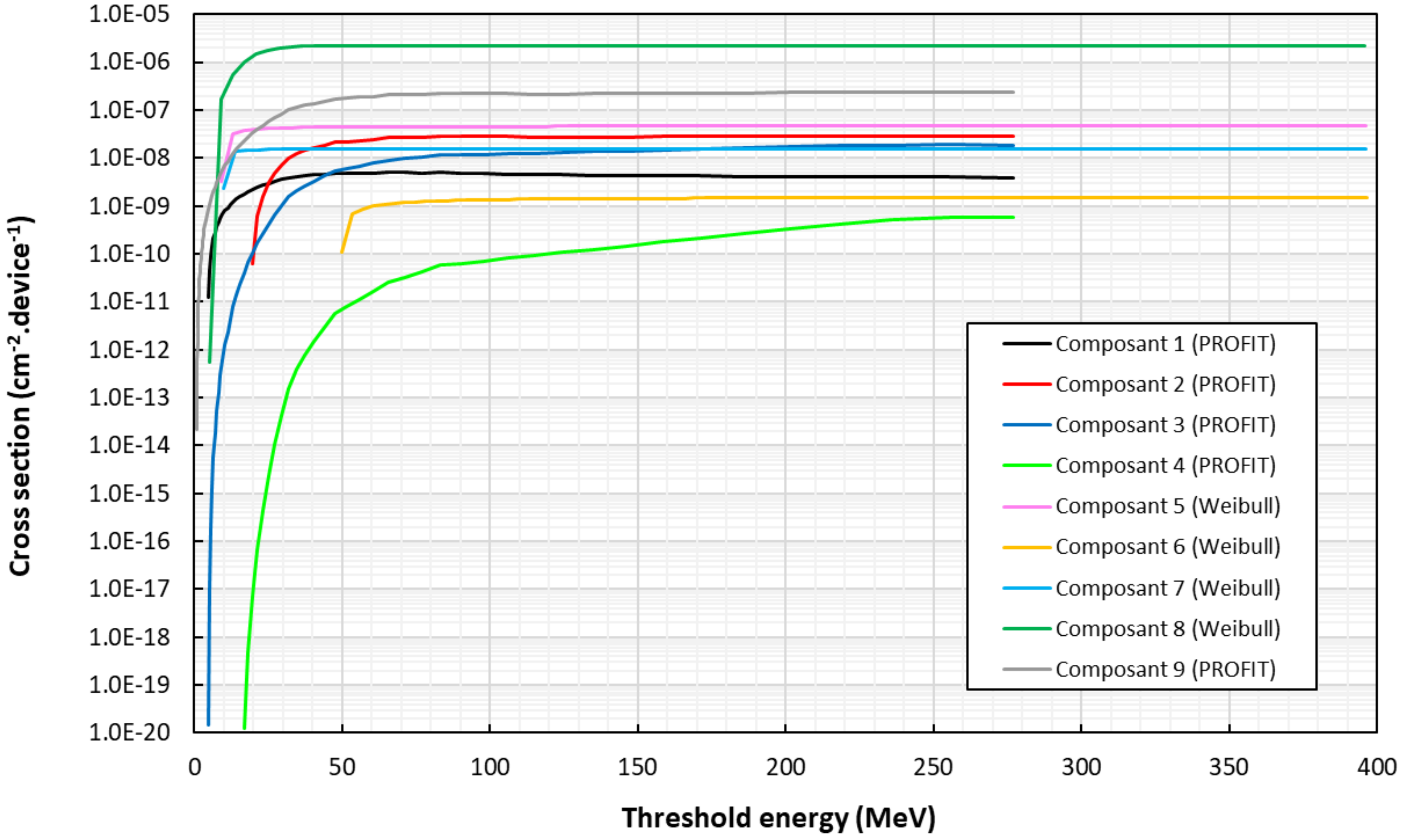
Missions and components

- Two missions:
  - LEO: 800 km 98°
  - EOR (LEO 250 km to GEO)
  - Neither GEO nor MEO (no sufficient energetic trapped protons to cross the shielding)

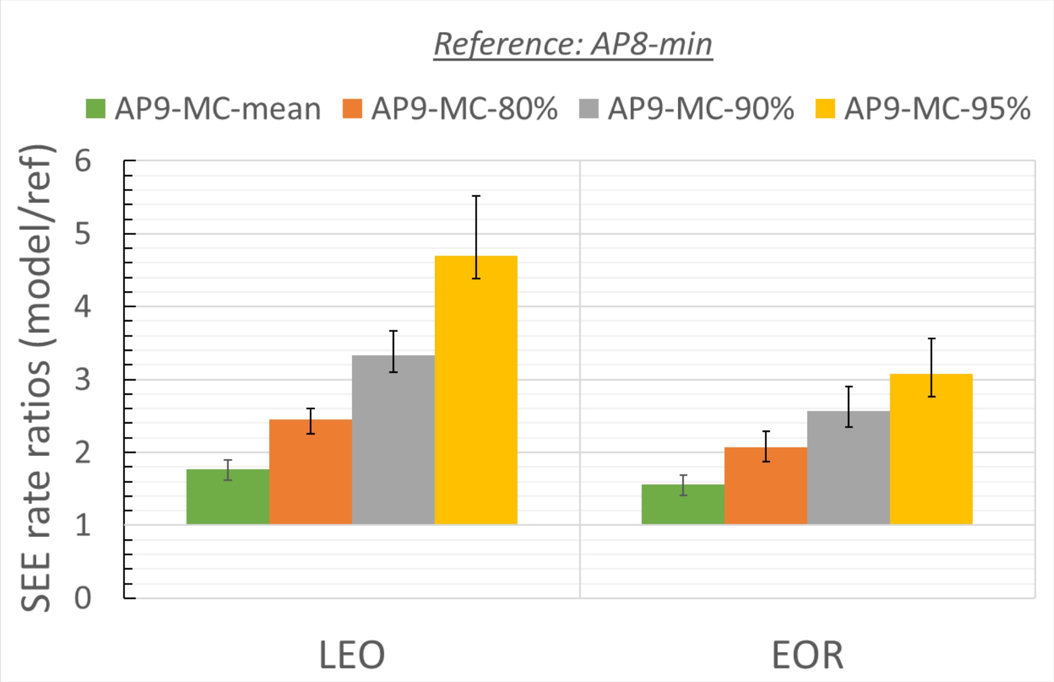
Mission	Trapped protons
LEO and EOR	AP8 min
	AP9 MC-mean
	AP9 MC-80/90/95%

Components

- Realistic component database
- Different cross section sensitivity profiles
- 9 components:
  - 4 with test data
  - 5 using Heavy Ions test data and PROFIT 90° model



SEE rate ratios VS Missions and models



- Ratios between 1.8 and 5.5,
- AP9 overestimates the SEE rate compared to AP8,
- High impact of the percentile parameter on the SEE rate,
- This overestimation has to be analyzed considering the margin applied by industry companies (ex: margin of 10 for ECSS standard).

Impact on solar cells degradation

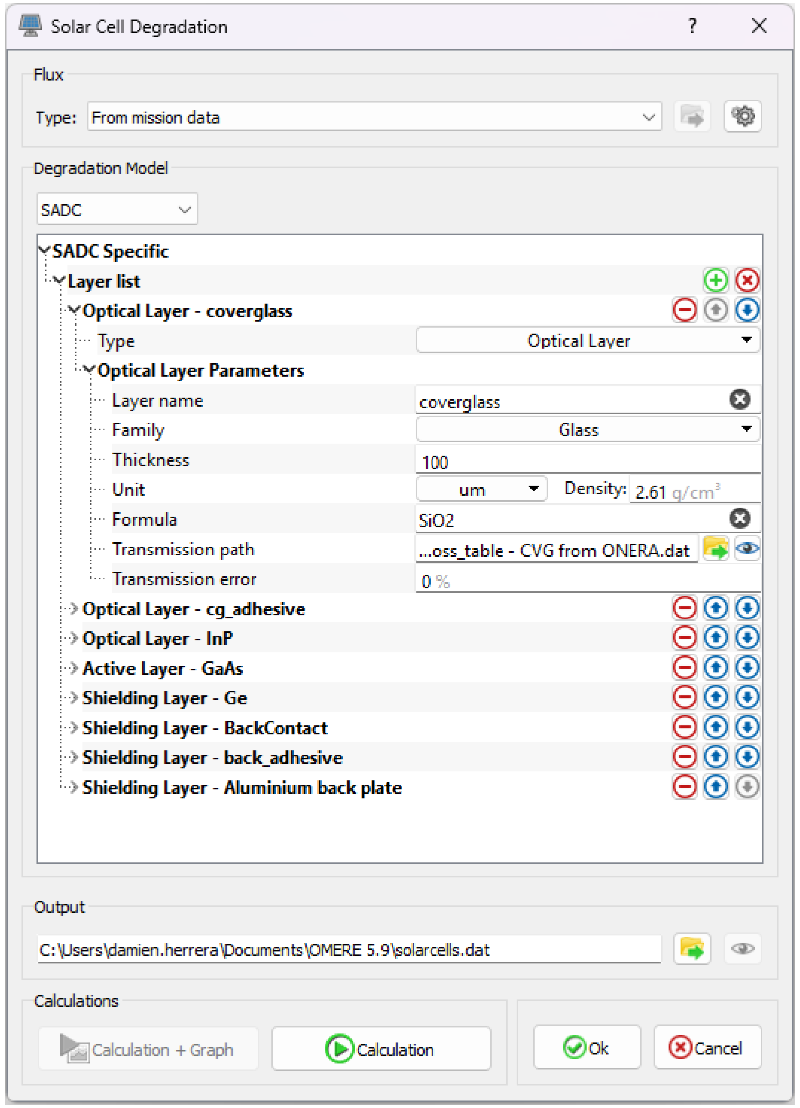
SADC tool

- SADC (**Solar Array Degradation Calculator**) developed in the frame of ESA ARTES AT-4F.126 project (TRAD prime with ONERA, OHB, ADS & TAS)
  - Integration of OMEP model developed by ONERA (p+ 30keV – 20 MeV for EOR orbit).

- Global Remaining Factors of different electrical parameters in output,
- Based on NRL method,
- Detailed model of the solar cell:
  - No limit on materials or shielding thicknesses
  - User can import NIEL data
  - No limitation on materials of the active layer

  → **Study of newer technologies**

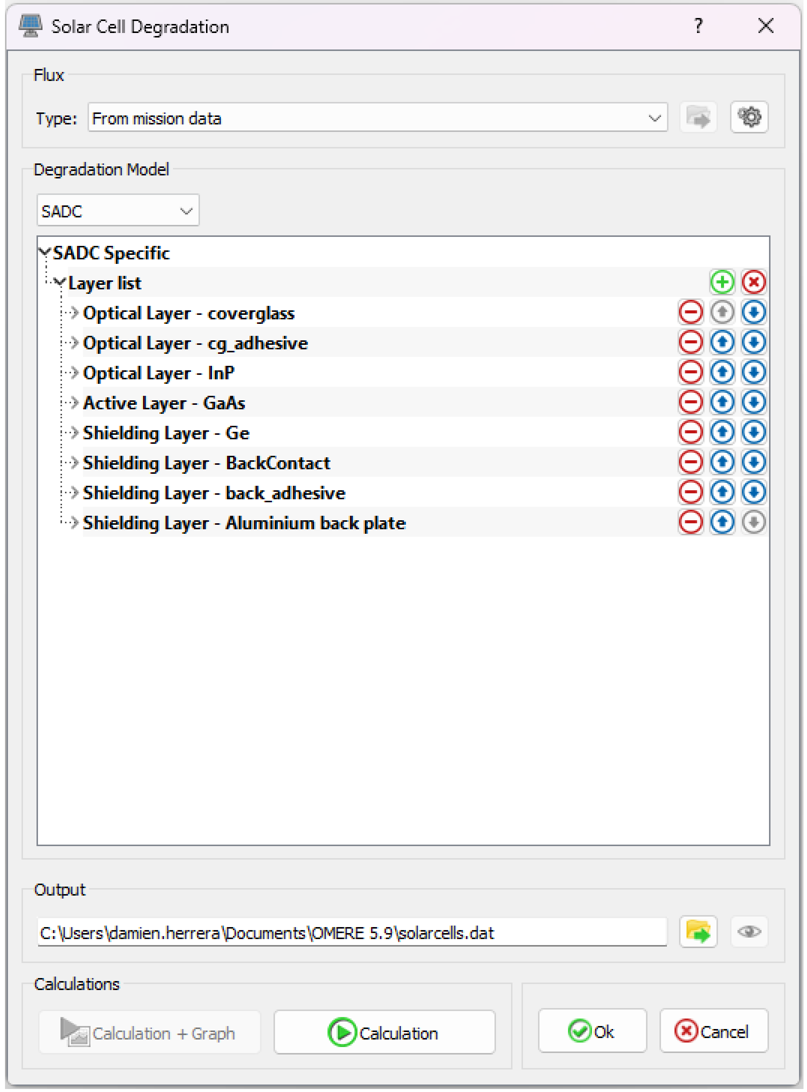
- Darkening of coverglass is now considered,
- Propagation of measurements uncertainties.



Solar cell model

- **3G30** cell, widely used in space industry
  - Active part: GaAs

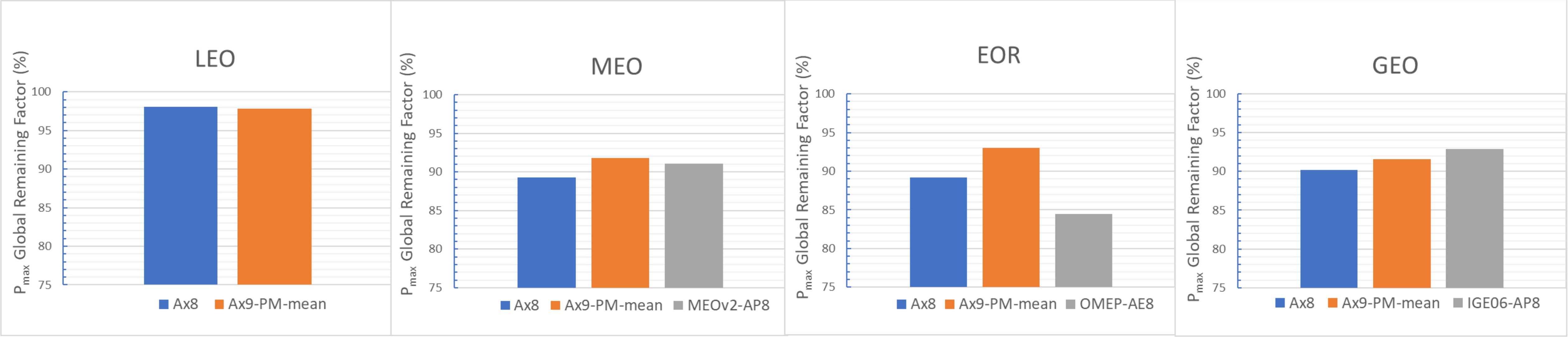
Layer	Type/Function	Material (Density in $g.cm^{-3}$)	Thickness (µm)
1	Coverglass	SiO_2 (2.61)	100
2	Adhesive	$SiOC_2H_6$ (1.03)	20
3	Optical	InP (4.81)	1
4	Active	GaAs (5.12)	2
5	Semi-conductor	Ge (5.35)	140
6	Back contact	Ag (10.5)	5
7	Shielding	Al (2.7)	1200



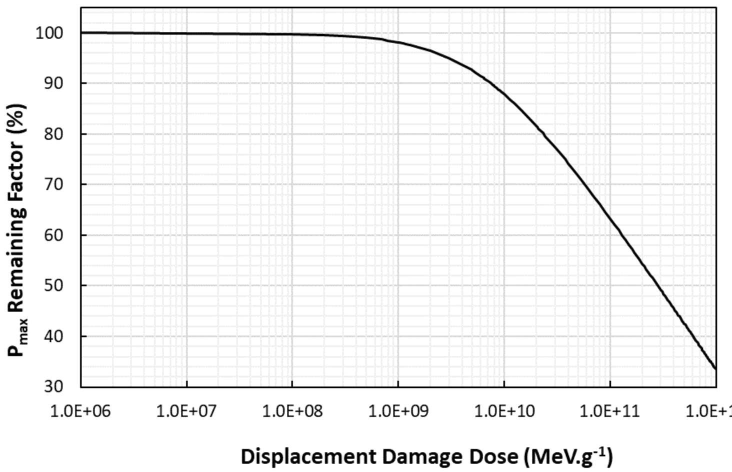
Missions and models

Mission	Trapped protons	Trapped electrons	Solar average protons
LEO (600km SSO) 10 years	AP8-min	AE8-max	ESP 90%
	AP9-PM-mean	AE9-PM-mean	
MEO (GALILEO) 12 years	AP8-min	MEOv2-average	ESP 85%
	AP8-min	AE8-max	
	AP9-PM-mean	AE9-PM-mean	
EOR (129 days)	OMEP	AE8-max	ESP 95%
	AP8-min	AE8-max	
	AP9-PM-mean	AE9-PM-mean	
GEO 15 years	AP8-min	IGE2006-average	ESP 80%
	AP8-min	AE8-max	
	AP9-PM-mean	AE9-PM-mean	

Solar cell degradation VS Mission and models



- LEO : Ax9 PM ≈ Ax8 → Low DDD so RF still in the first part of the curve
- MEO : MEOv2 worst-case compared to Ax9 (DDD mainly due to e-)
- EOR : Ax8 worst-case compared to Ax9 (both p+ and e-)
- GEO : Ax9 worst-case compared to IGE2006 (due to e-)



Conclusion

- Using IRENE models instead of historical ones has a noticeable impact,
- It strongly depends of the effect and the mission considered,
- Lower solar cell degradation compared to Ax8,
- Higher SEE rate compared to AP8 min,
- Dose level, compared to Ax8, depends of the mission.

Thank you for your attention

For further information on:

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www.rayxpert.com – www.r2cots.com

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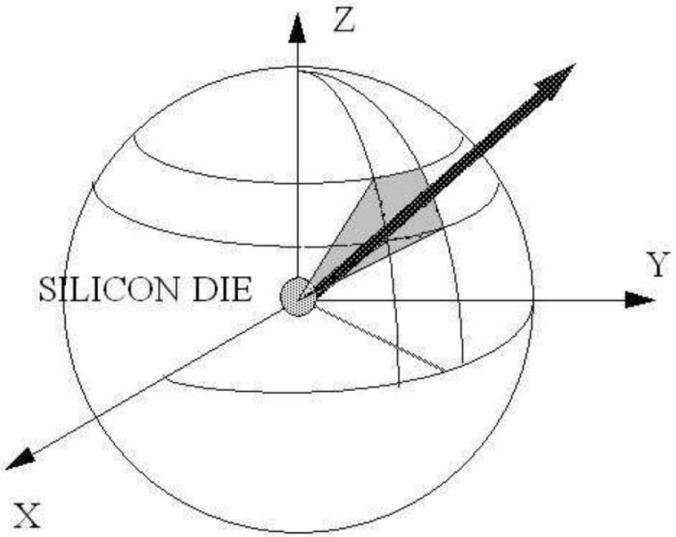
trad@trad.fr

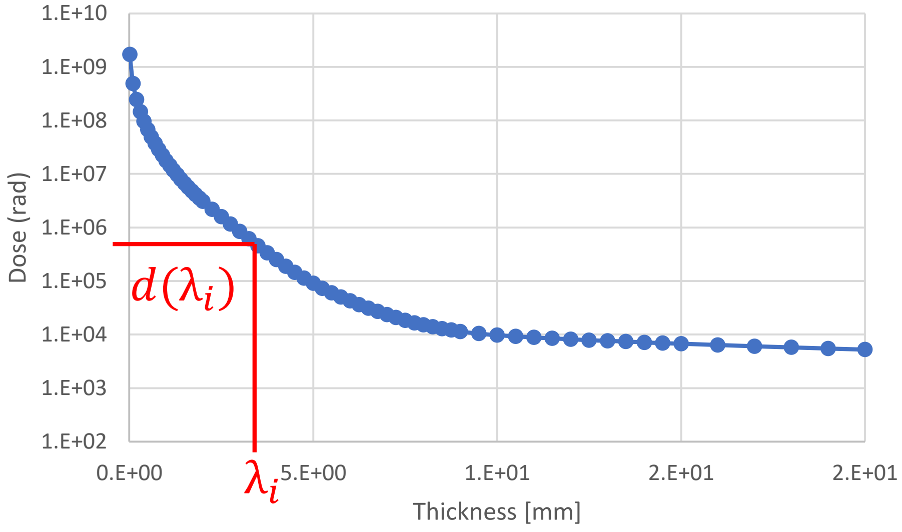
+33 (0)5 61 00 95 60

Back-up

Ray-Tracing calculation

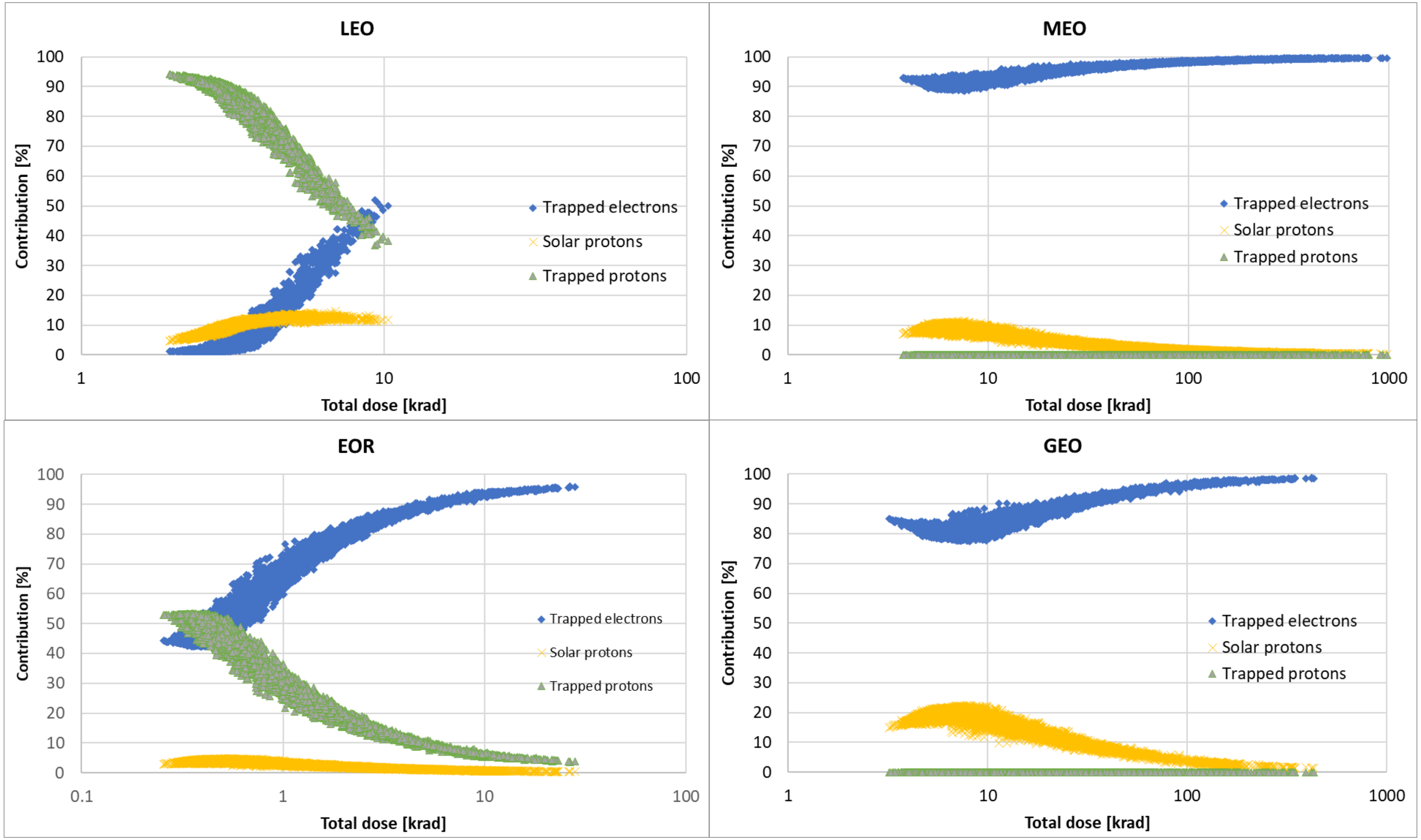
- Ray-Tracing
  - Division of the sphere surrounding the sensitive area in identical solid angles,
  - Calculation of the dose in each solid angle based on the dose-depth curve,
  - Average over all the solid angles.



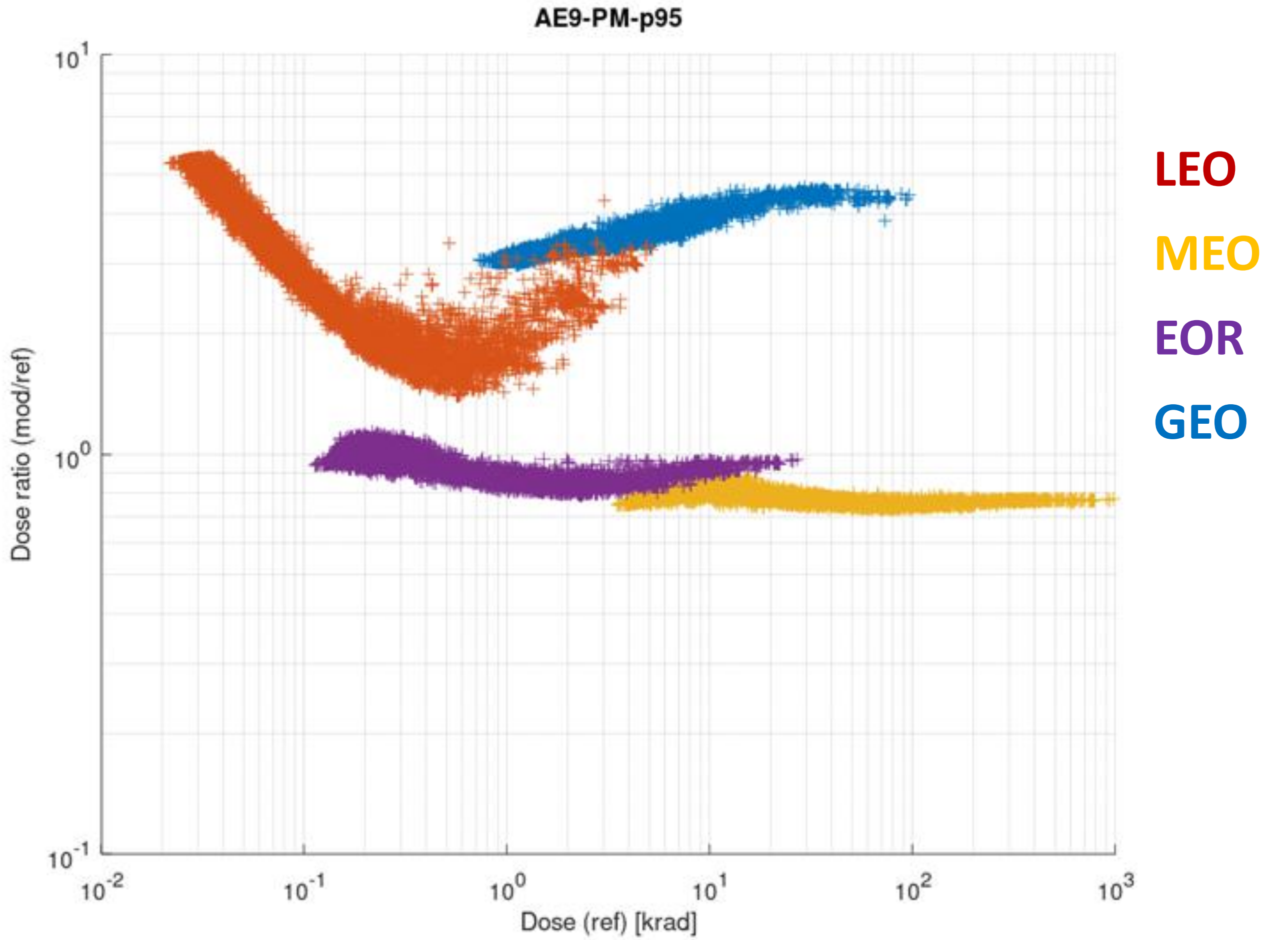


$$D = \sum_{i=1}^{N} \frac{d(\lambda_i)\Omega_i}{4\pi}$$

Dose contribution

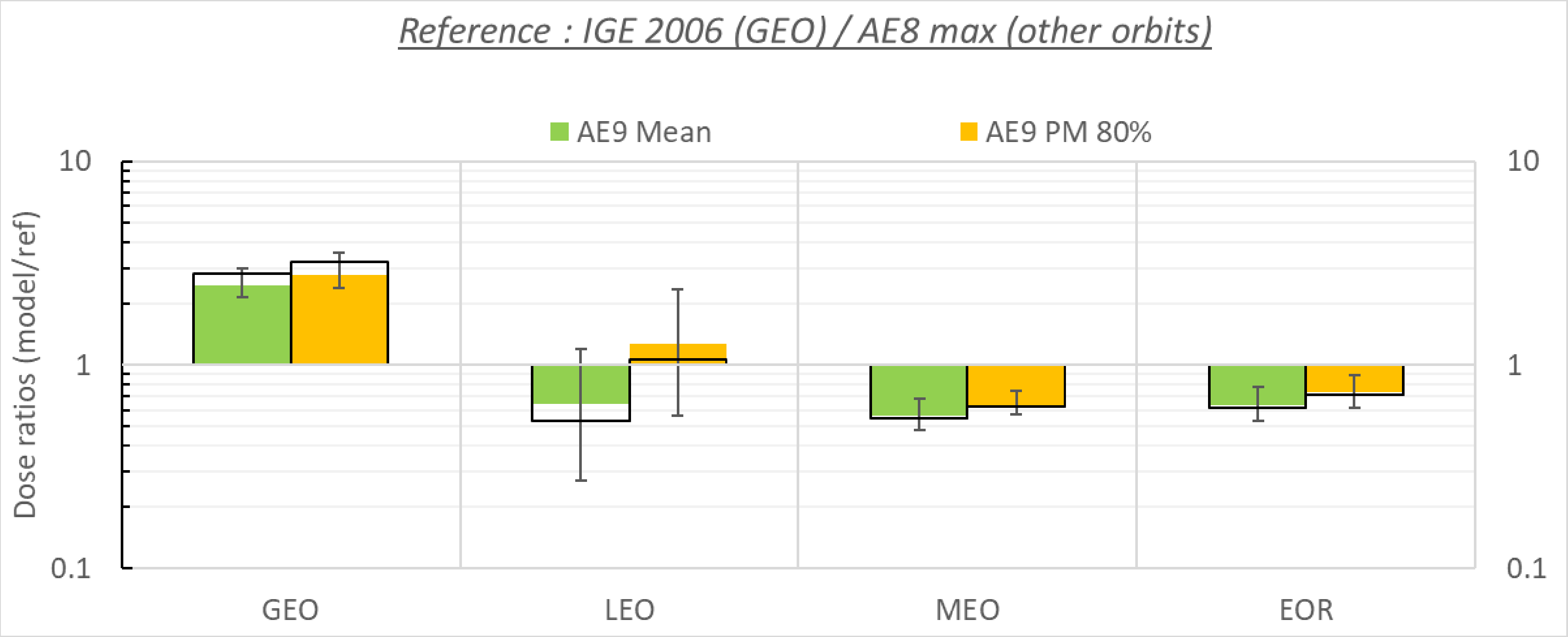


AE9 and missions



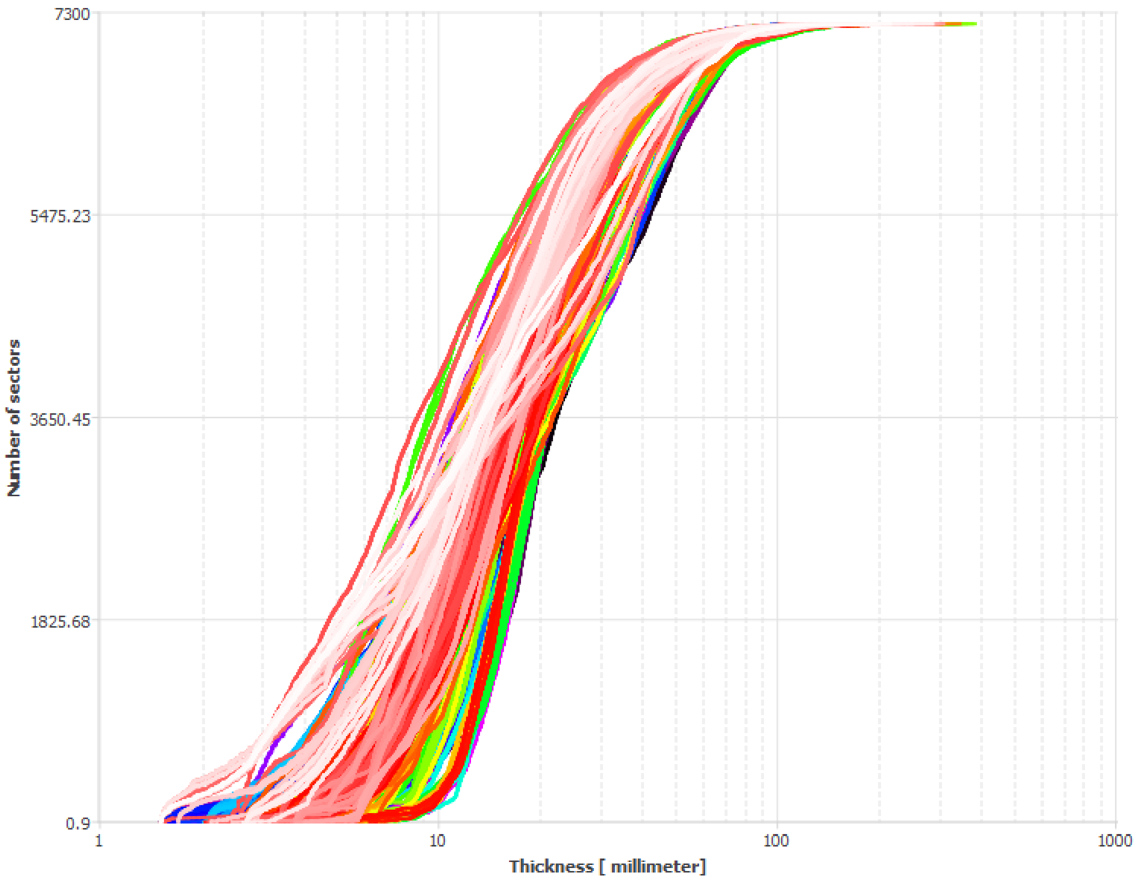
- LEO:
  - Ratio strongly dependent of the received dose level,
  - For dose level > 1krad, ratios between 1.5 and 3.

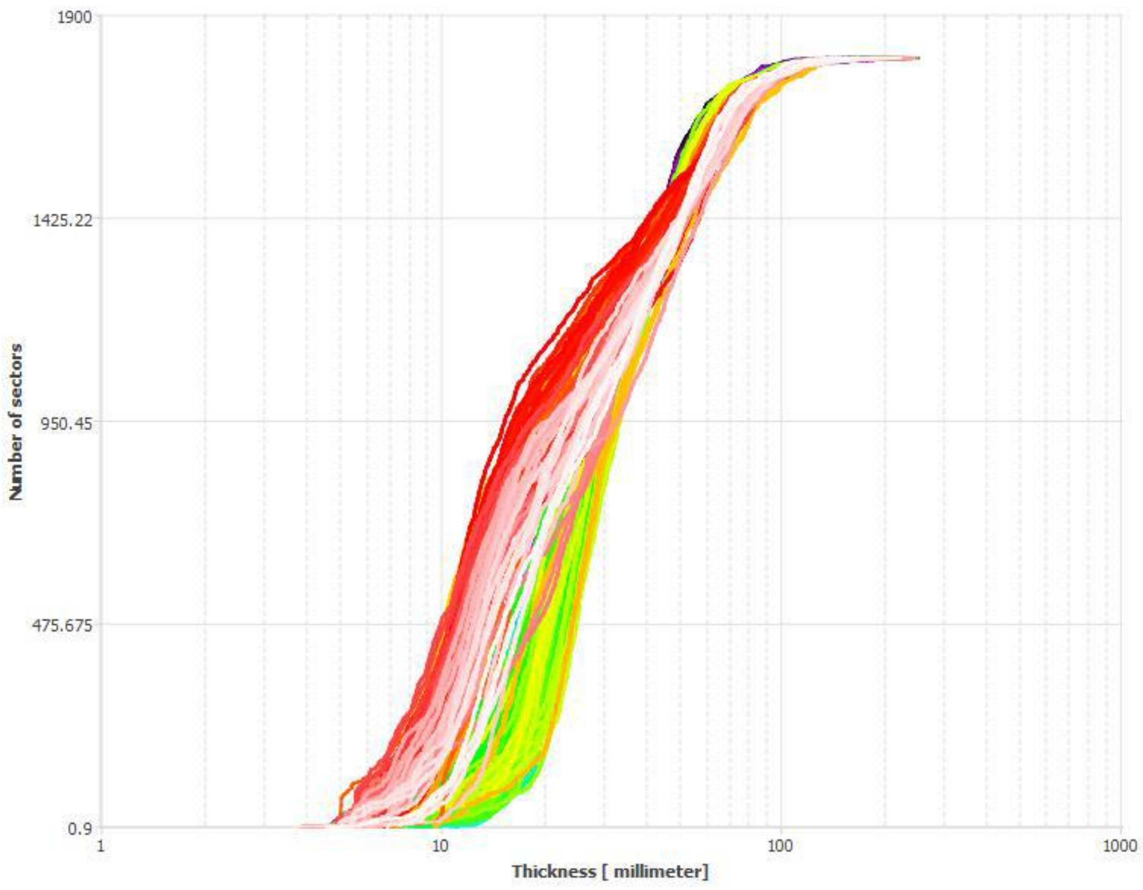
Dose ratio in Reverse Monte-Carlo Trapped electrons



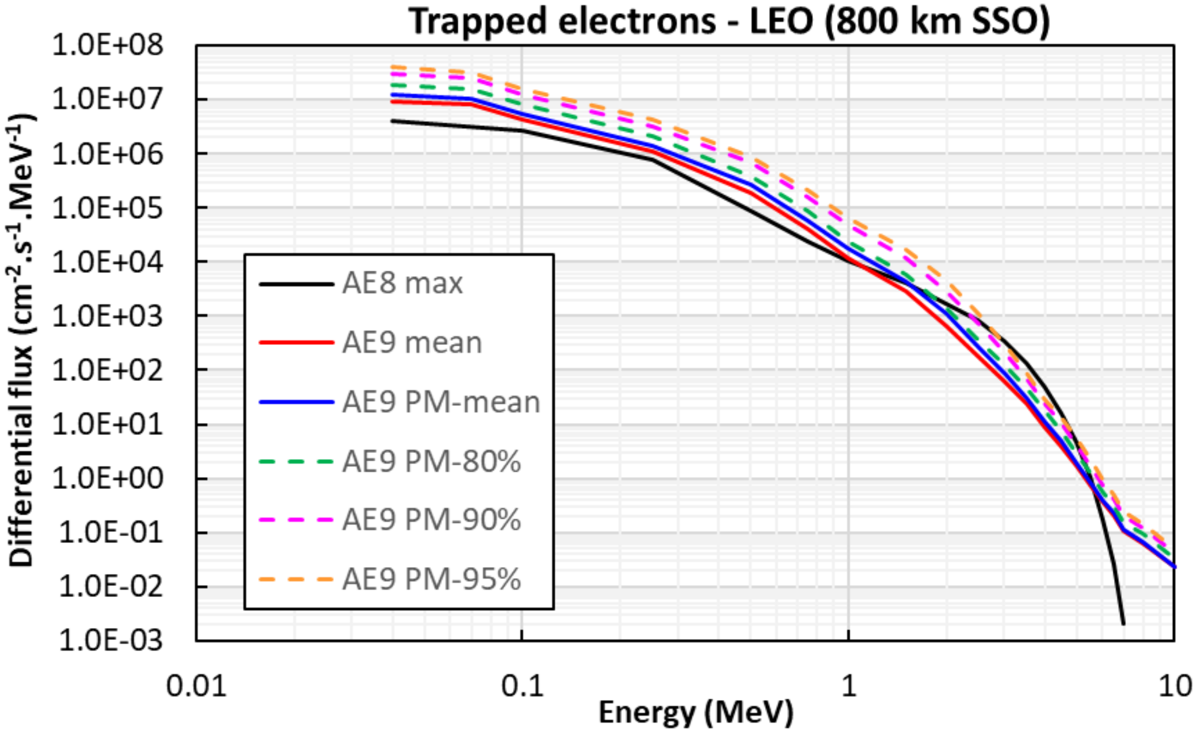
Representativeness of 3D models

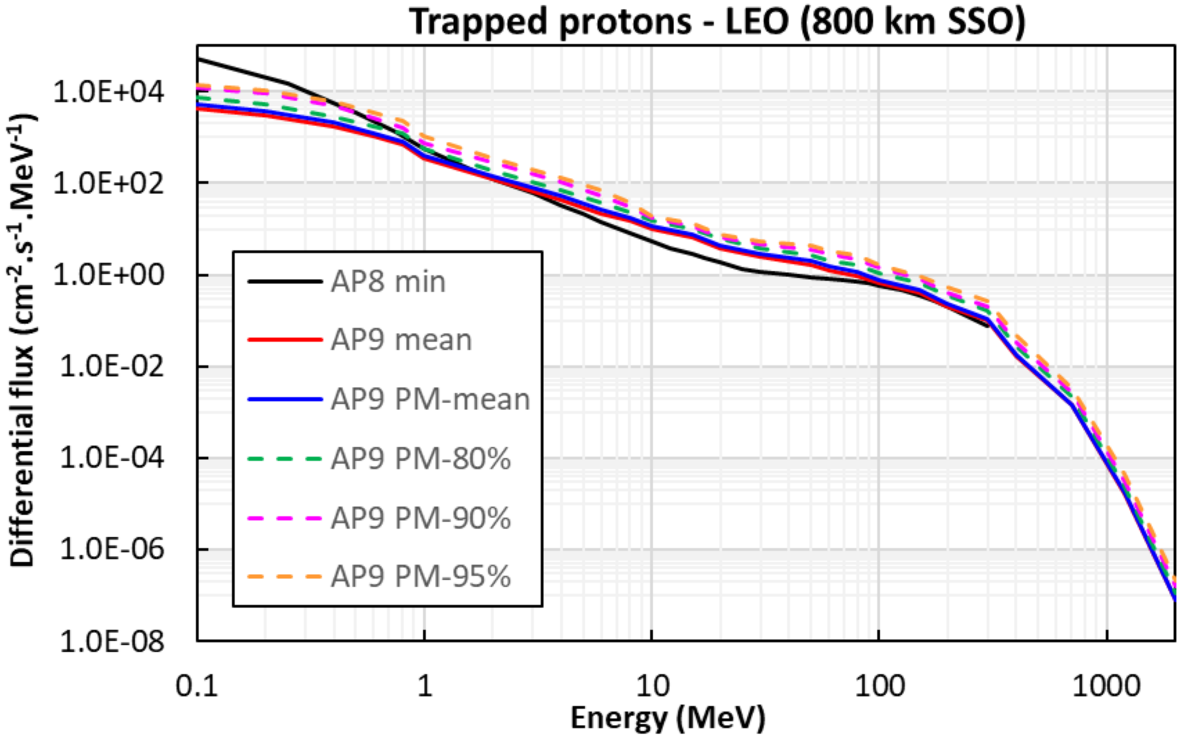
- Shielding profile of detectors for G1_unitA and JASON_ICARE models



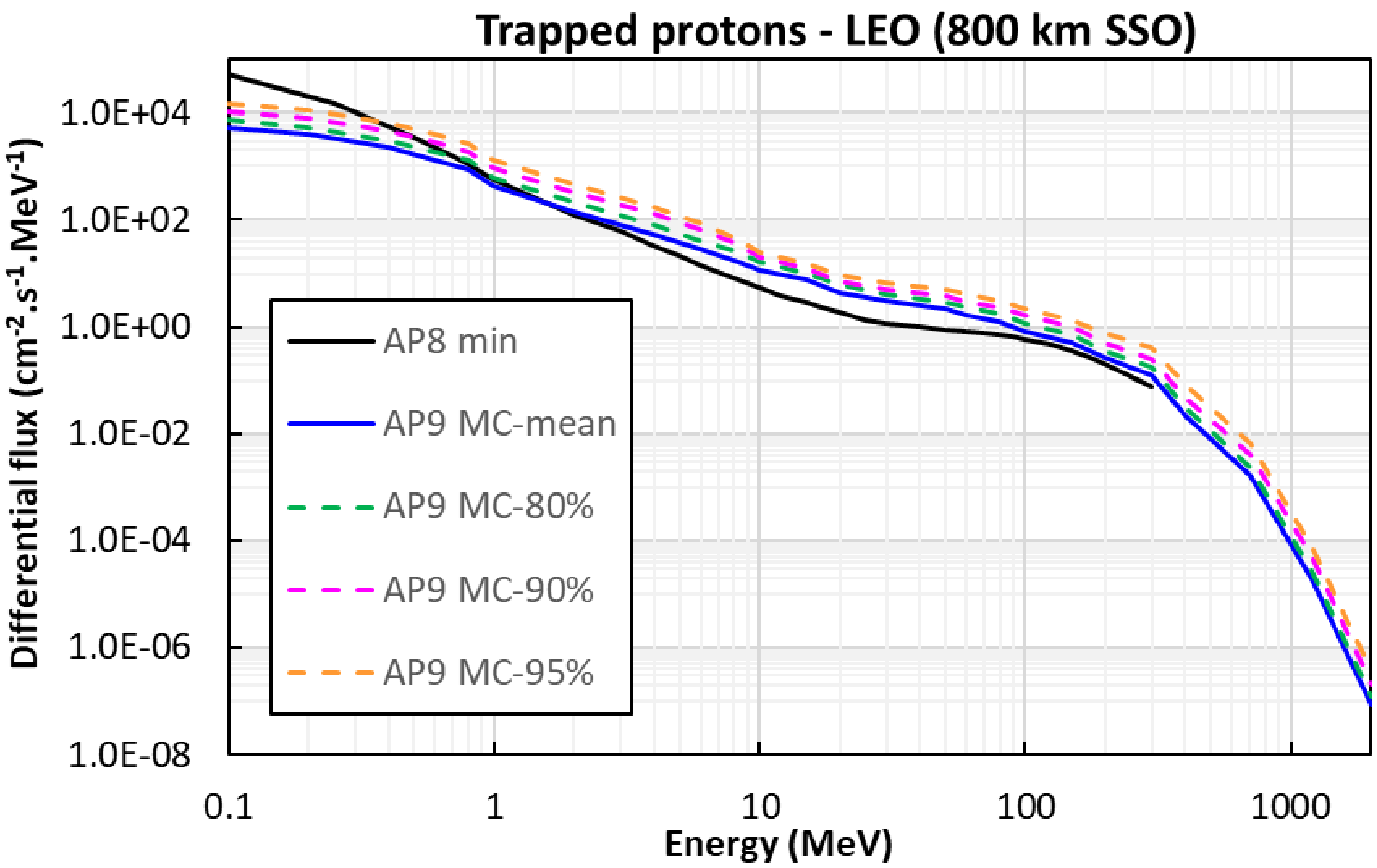


TID: LEO (800km SSO)

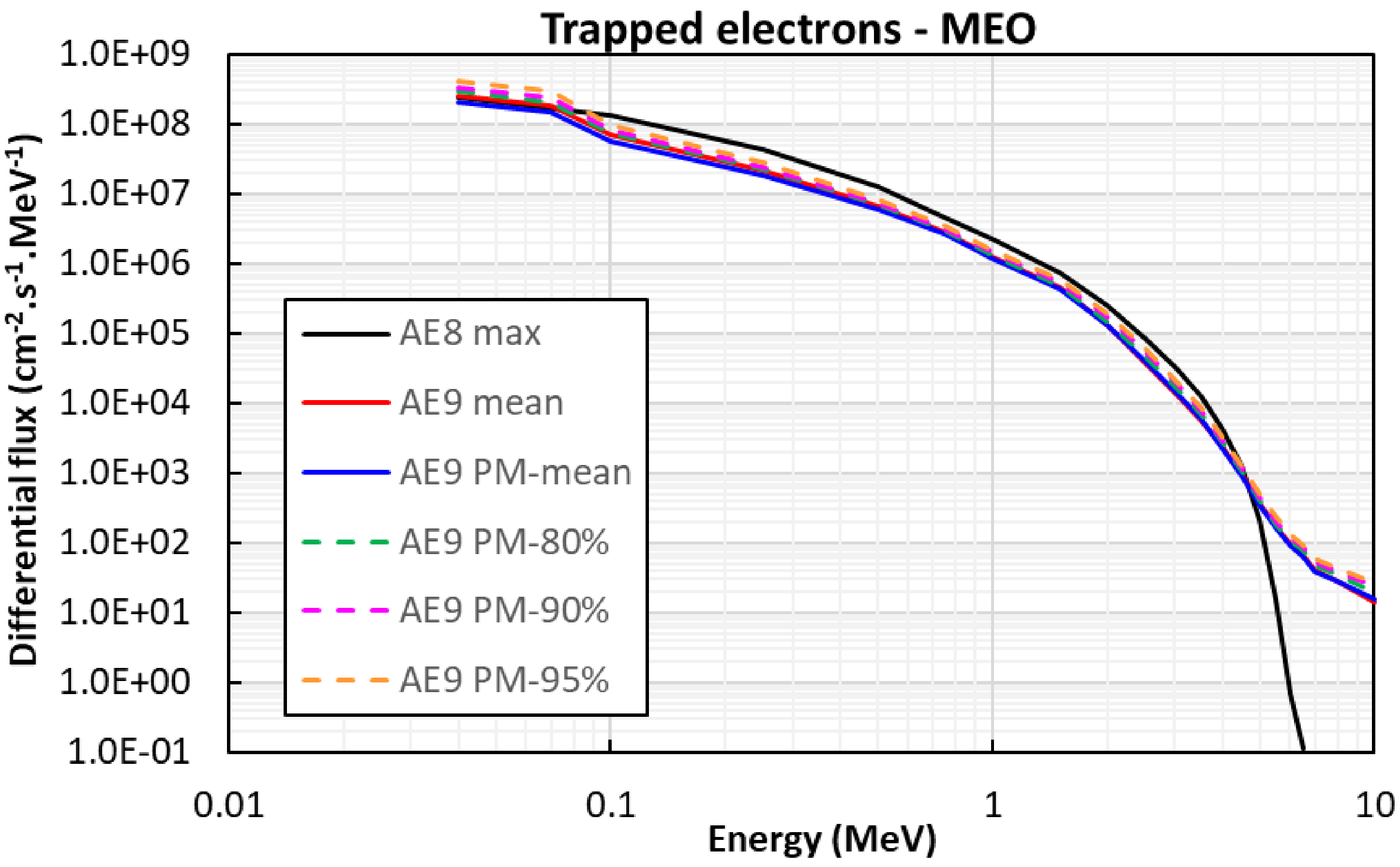




SEE: LEO (800km SSO)

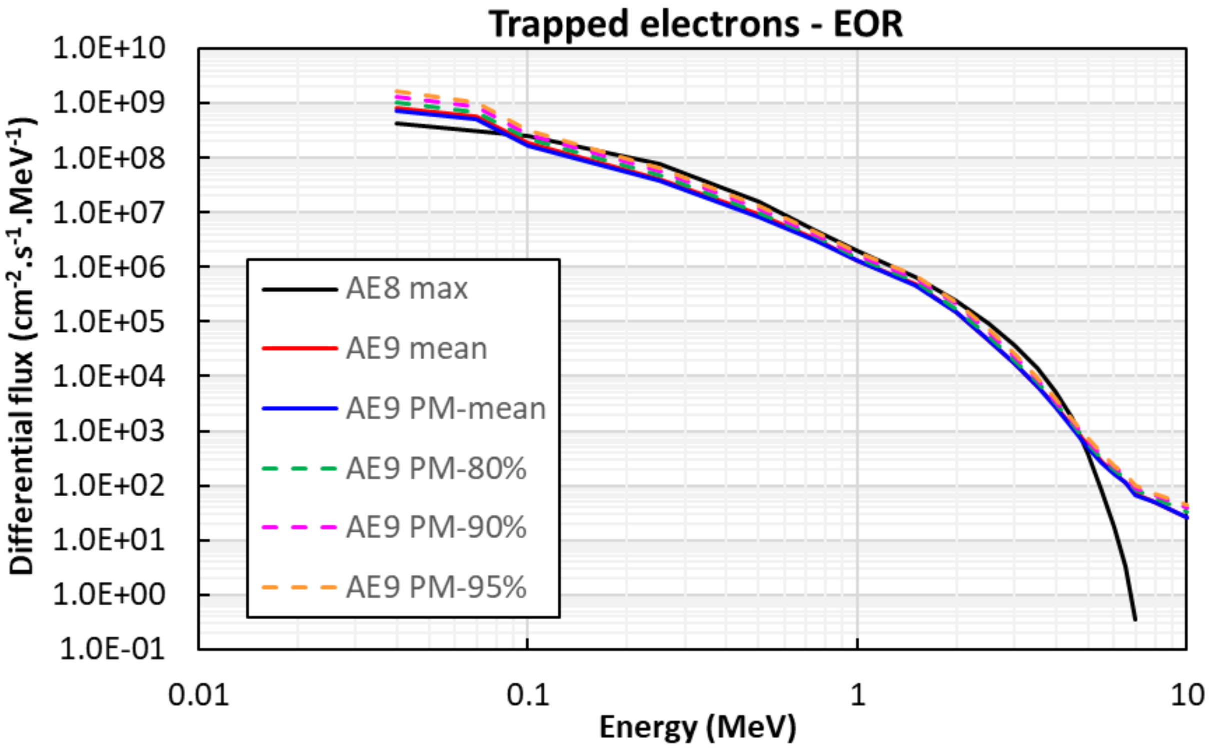


TID: MEO

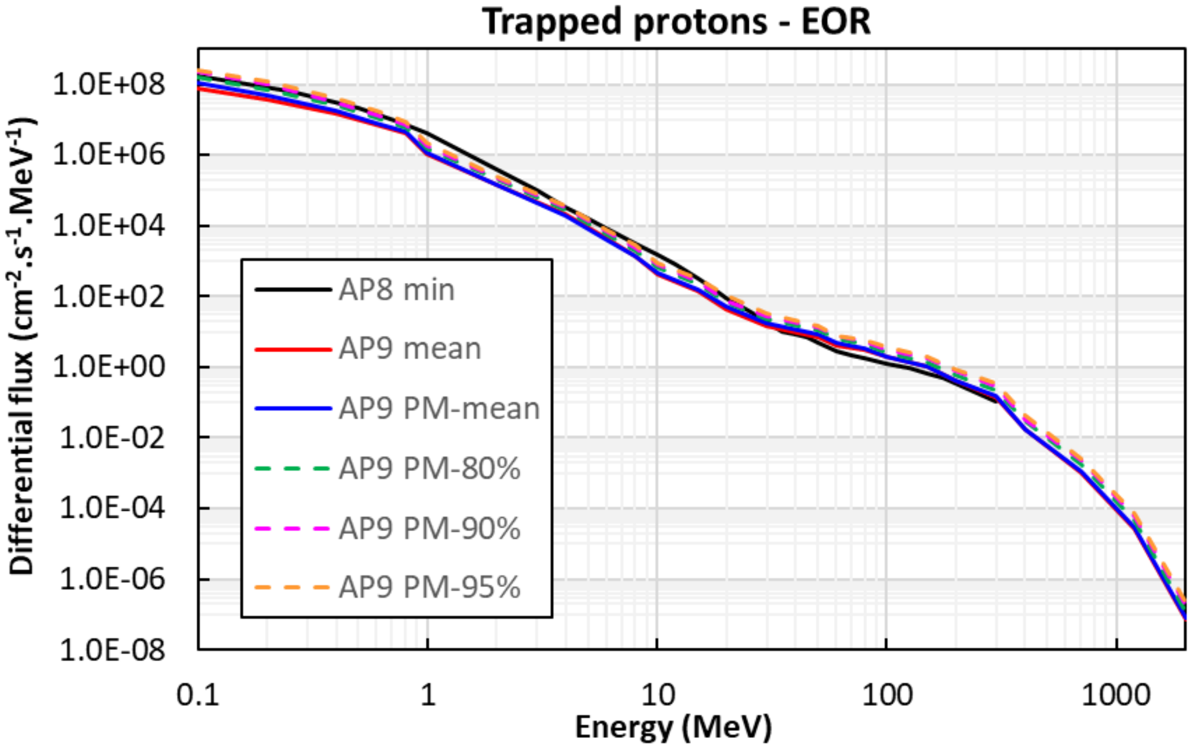


Trapped electrons - MEO
Differential flux (cm^{-2}.s^{-1}.MeV^{-1})
1.0E+09
1.0E+08
1.0E+07
1.0E+06
1.0E+05
1.0E+04
1.0E+03
1.0E+02
1.0E+01
1.0E+00
1.0E-01
0.01
0.1
1
10
Energy (MeV)
AE8 max
AE9 mean
AE9 PM-mean
AE9 PM-80%
AE9 PM-90%
AE9 PM-95%

TID: EOR

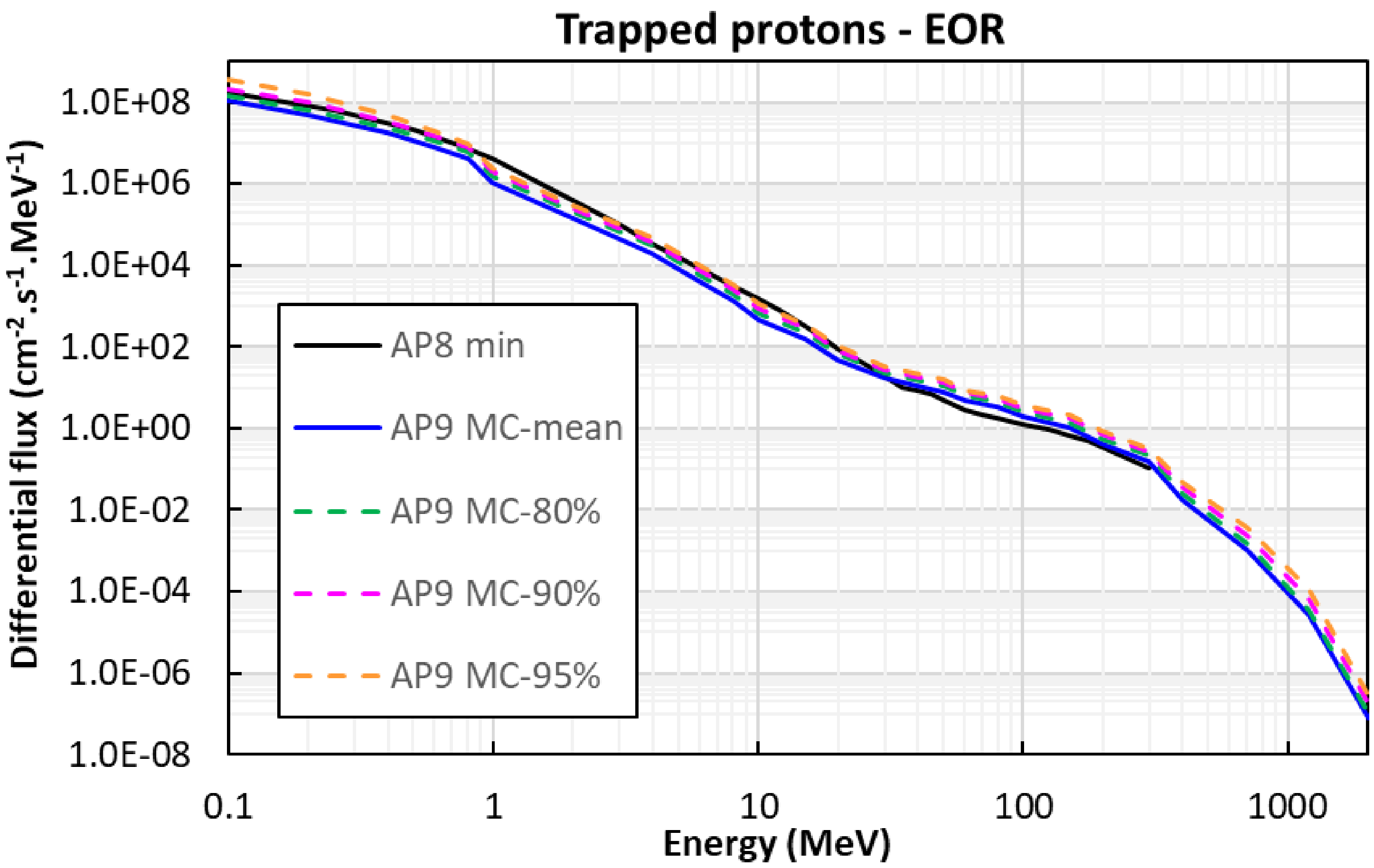


Trapped electrons - EOR
Differential flux (cm^{-2}.s^{-1}.MeV^{-1})
1.0E+10
1.0E+09
1.0E+08
1.0E+07
1.0E+06
1.0E+05
1.0E+04
1.0E+03
1.0E+02
1.0E+01
1.0E+00
1.0E-01
0.01
0.1
1
10
Energy (MeV)
AE8 max
AE9 mean
AE9 PM-mean
AE9 PM-80%
AE9 PM-90%
AE9 PM-95%

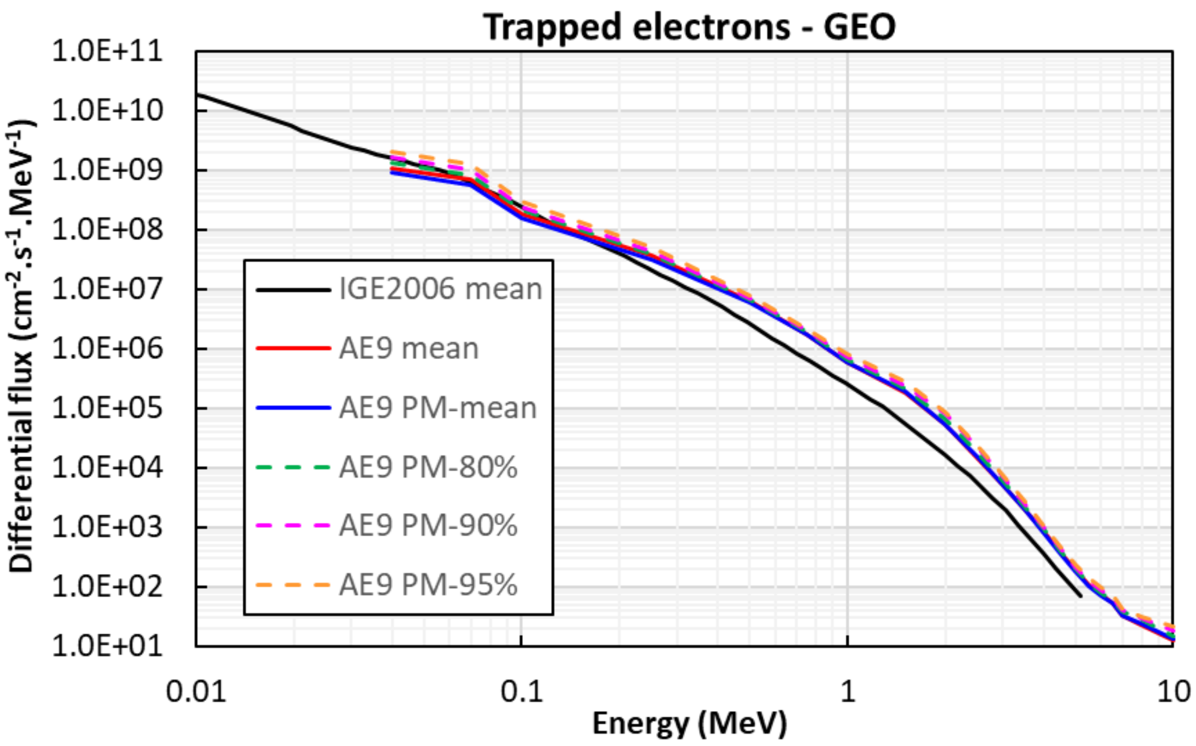


Trapped protons - EOR
Differential flux (cm^{-2}.s^{-1}.MeV^{-1})
1.0E+08
1.0E+06
1.0E+04
1.0E+02
1.0E+00
1.0E-02
1.0E-04
1.0E-06
1.0E-08
0.1
1
10
100
1000
Energy (MeV)
AP8 min
AP9 mean
AP9 PM-mean
AP9 PM-80%
AP9 PM-90%
AP9 PM-95%

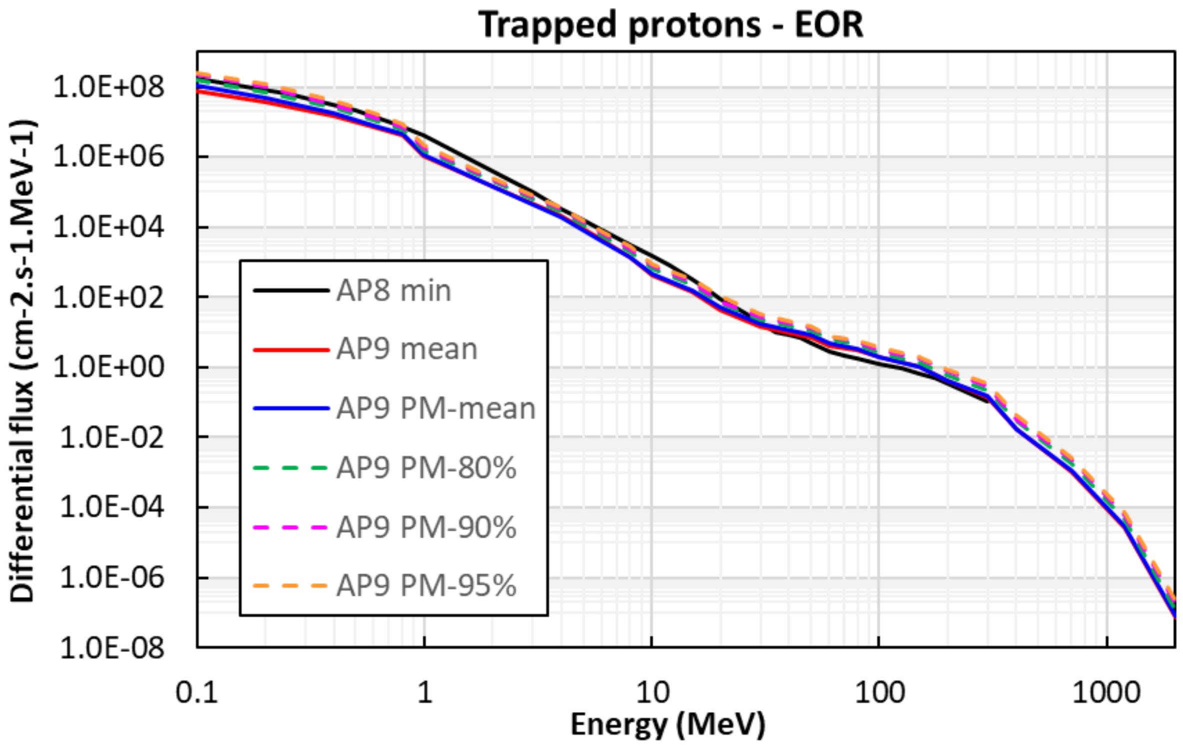
SEE: EOR


Trapped protons - EOR
Differential flux (cm-2.s-1.MeV-1)
1.0E+08
1.0E+06
1.0E+04
1.0E+02
1.0E+00
1.0E-02
1.0E-04
1.0E-06
1.0E-08
0.1
1
10
100
1000
Energy (MeV)
AP8 min
AP9 MC-mean
AP9 MC-80%
AP9 MC-90%
AP9 MC-95%

TID: GEO

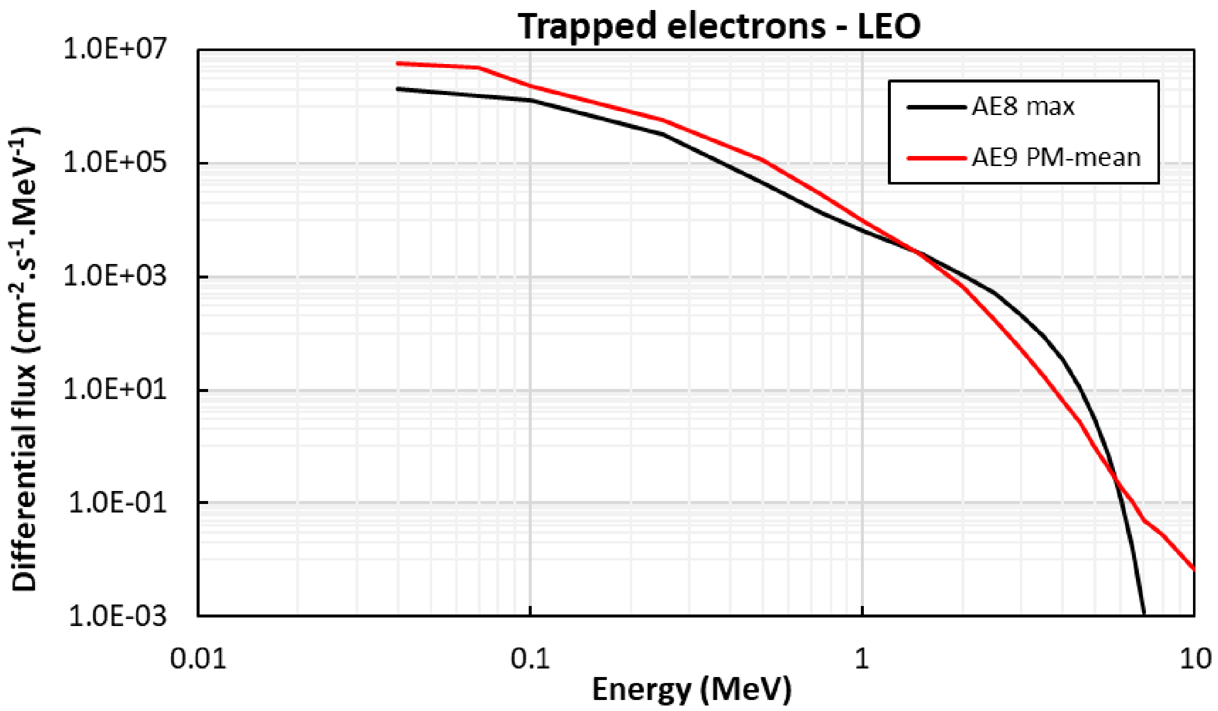


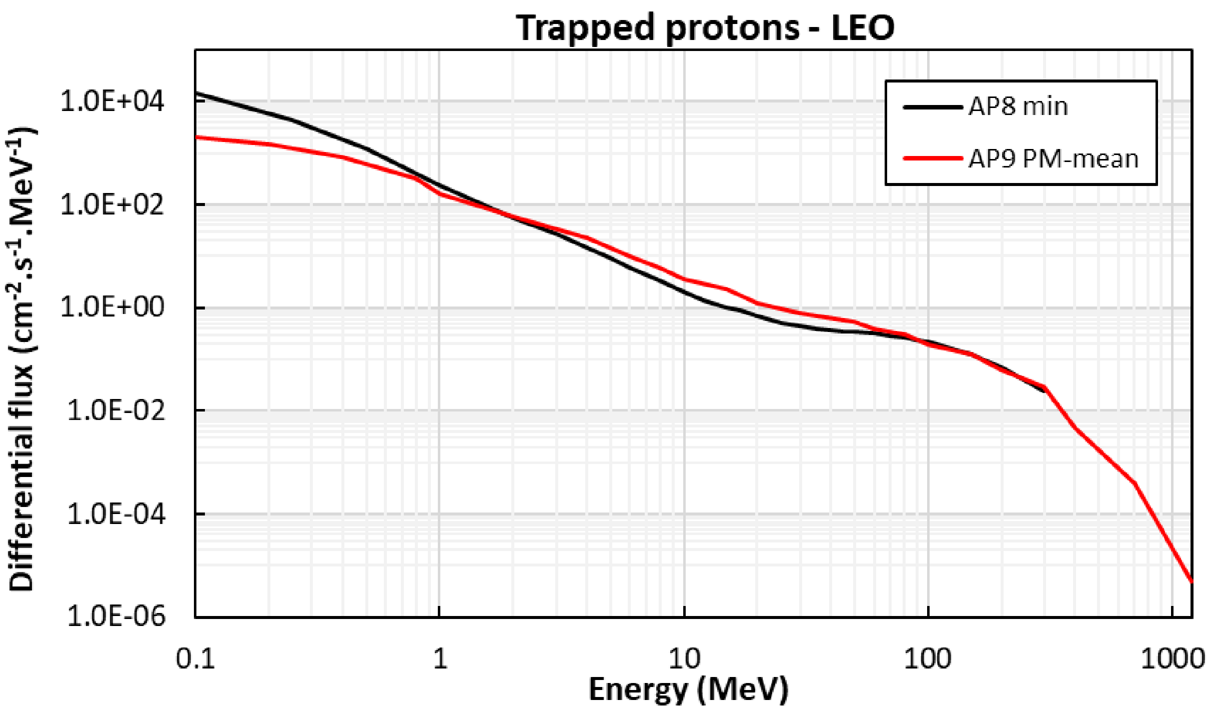
Trapped electrons - GEO
Differential flux (cm-2.s-1.MeV-1)
1.0E+11
1.0E+10
1.0E+09
1.0E+08
1.0E+07
1.0E+06
1.0E+05
1.0E+04
1.0E+03
1.0E+02
1.0E+01
0.01
0.1
1
10
Energy (MeV)
IGE2006 mean
AE9 mean
AE9 PM-mean
AE9 PM-80%
AE9 PM-90%
AE9 PM-95%



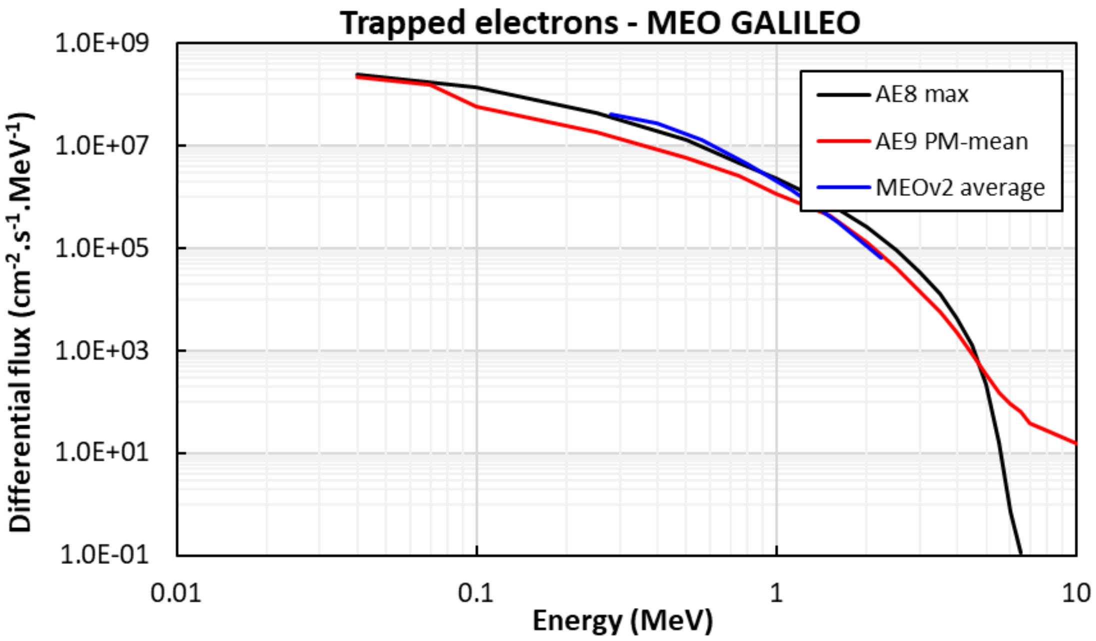
Trapped protons - EOR
Differential flux (cm-2.s-1.MeV-1)
1.0E+08
1.0E+06
1.0E+04
1.0E+02
1.0E+00
1.0E-02
1.0E-04
1.0E-06
1.0E-08
0.1
1
10
100
1000
Energy (MeV)
AP8 min
AP9 mean
AP9 PM-mean
AP9 PM-80%
AP9 PM-90%
AP9 PM-95%

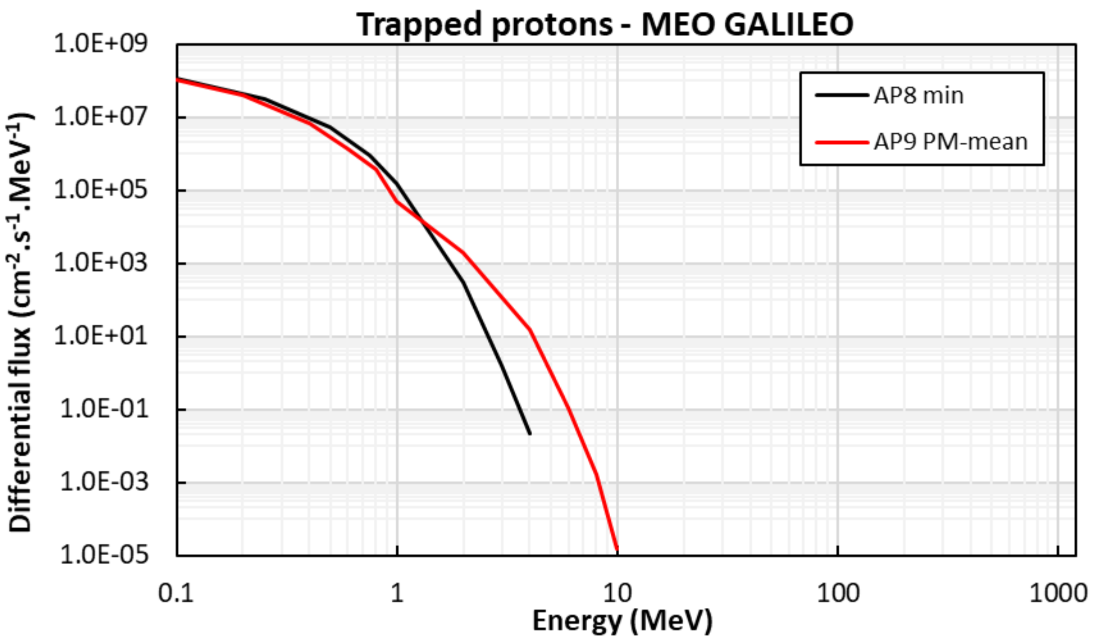
Solar cell degradation: LEO (600km SSO)



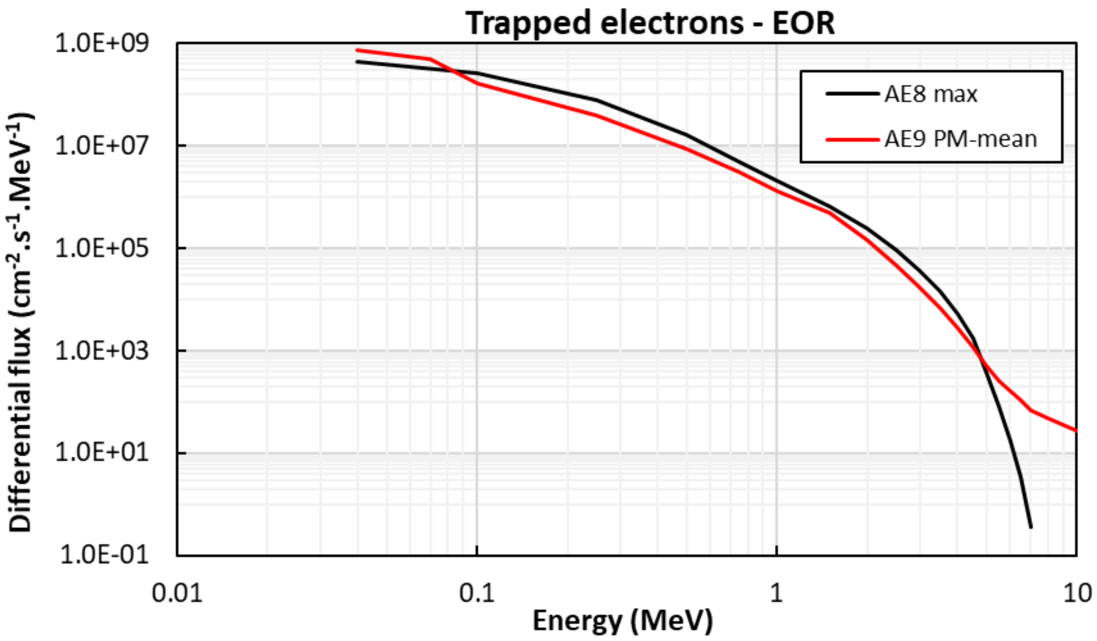


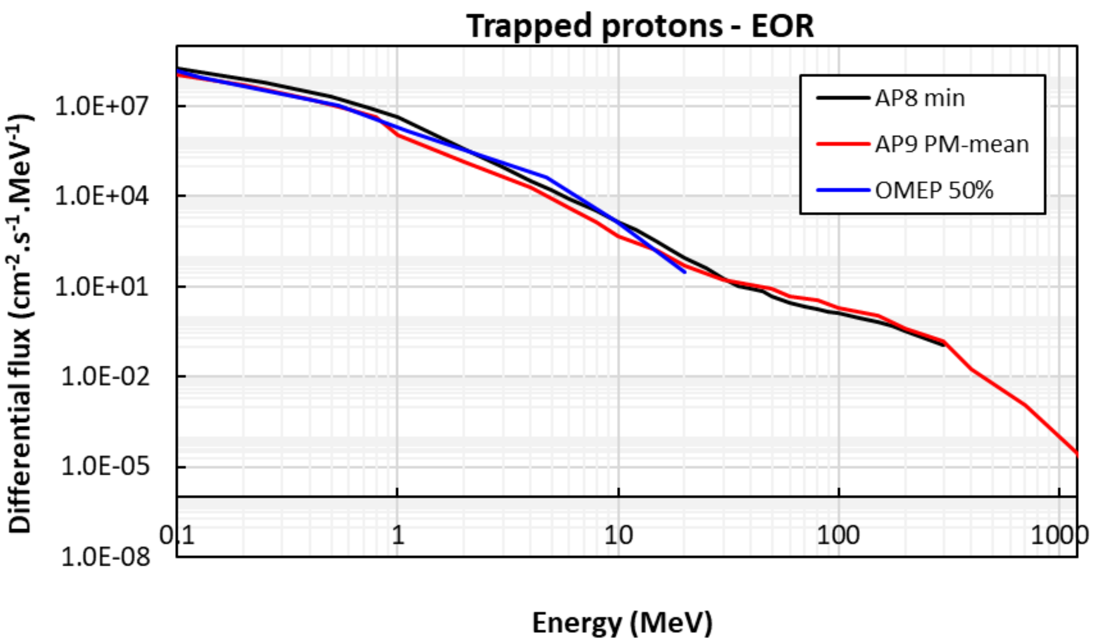
Solar cells degradation: MEO





Solar cells degradation: EOR





Solar cells degradation: GEO