Worst-Case Circular Orbits and AX9/AX8 Comparison

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Worst Case Study

What are the worst case TID and instantaneous flux in different orbital environments? Which orbits are the worst?

General Earth Orbit Radiation Study

LEO	Circular, 400-1500 km, steps of 100km; 0-100° inclination, steps of 10°
MEO	Circular, 10000-22000 km, steps of 1000km; 0-70° inclination, steps of 10°
GEO	Circular, 35786 km; 0-70° inclination, steps of 10°

Expected Output

Worst case orbit and fluence numbers for each of the radiation environment components listed below

Total Ionizing Dose (TID) and Displacement Damage (DD)		
Environment Input	**Models**	**Notes**
Trapped Electrons	AE9 Mean V1.50.001	Worst case single orbit over 1, 3, 5, 7, 11 year fluence with RDF=2 applied
Plasma Electrons	Plasma electron model included with AE9/AP9 model V1.50.001	Worst case single orbit over 1, 3, 5, 7, 11 year fluence with RDF=2 applied
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Solar Protons	ESP/Psychic 95% environment	1, 3, 5, 7, 11 year fluence at solar max with RDF=2 applied
Method of Joining Trapped and Solar Protons	Summed	
TID/DD Hazard Calculation	**Model Setup/Parameters**	**Notes**
Effects Code	NOVICE	Silicon Detector
Geometry	1D Al Solid Sphere and Slab	Slab dose for surface TID/DD
Shielding	4.0e-4 mil to ~1200 mil (1e-5mm to ~30mm) Al	

Single Event Effects		
Environment Input	**Models**	**Notes**
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Method of Joining Trapped and Solar Protons	None	Both conditions specified
TID/DD Hazard Calculation	**Model Setup/Parameters**	**Notes**
Effects Code	CREME96	
Geometry	CREME96 defaults	
Shielding	CREME96 defaults	25 mils (0.6 mm)

Charging Environments		
Environment Input	**Models**	**Notes**
Plasma Electrons	Values calculated	Values calculated
Trapped Electrons	AE9 peak flux V1.50.001	200 cases, 99% environment

Peak Flux Environments		
Environment Input	**Models**	**Notes**
Trapped Protons	AP9 peak flux V1.50.001	200 cases, 99% environment
Trapped Electrons	AE9 peak flux V1.50.001	200 cases, 99% environment

IRENE Task Plan

Run Simulations

- At each specified altitude and latitude.
- GEO is a special case—longitude must be considered.

→ Calculate the dose-depth curve for each simulation.

→ Identify worst case dose-depth envelope and corresponding orbits. These are the worst orbits.

→ For these worst orbits only, run Monte Carlo simulations at 99% confidence.

→ Select peak flux values observed at each energy level in the model. This estimates the extreme peak flux spectrum.

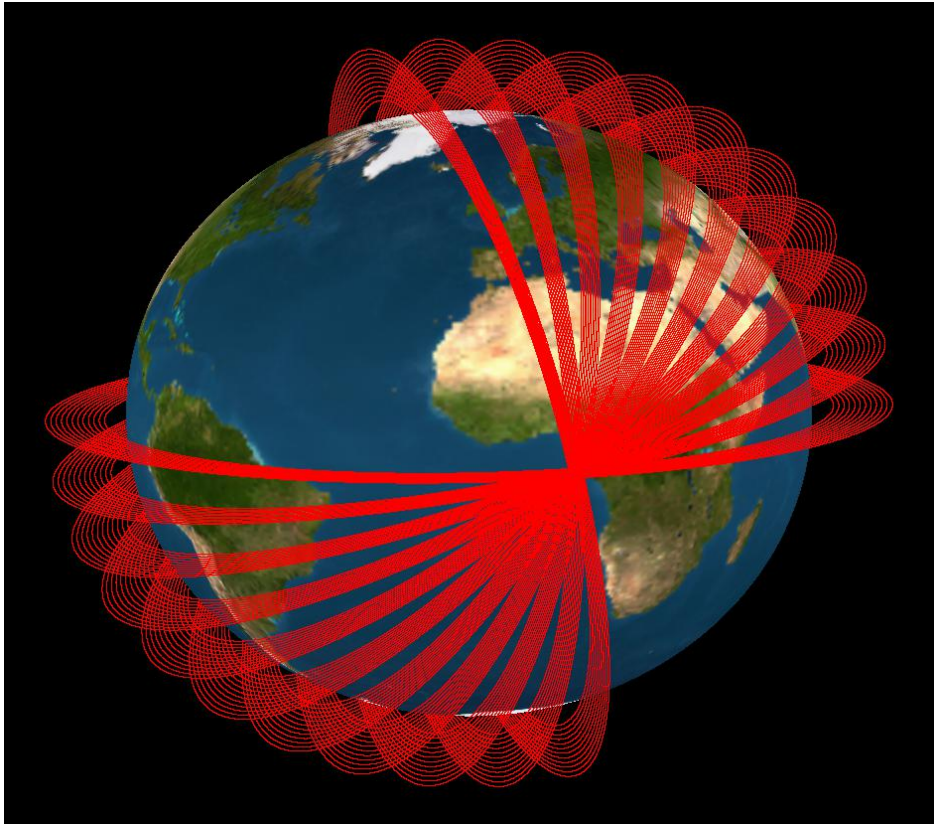
IRENE LEO Dose Calculations

Circular orbits

Altitudes: 400-1500 km, 100 km steps.

Inclinations: 0-100º, 10º steps.

Duration: 10 days, 10s steps.



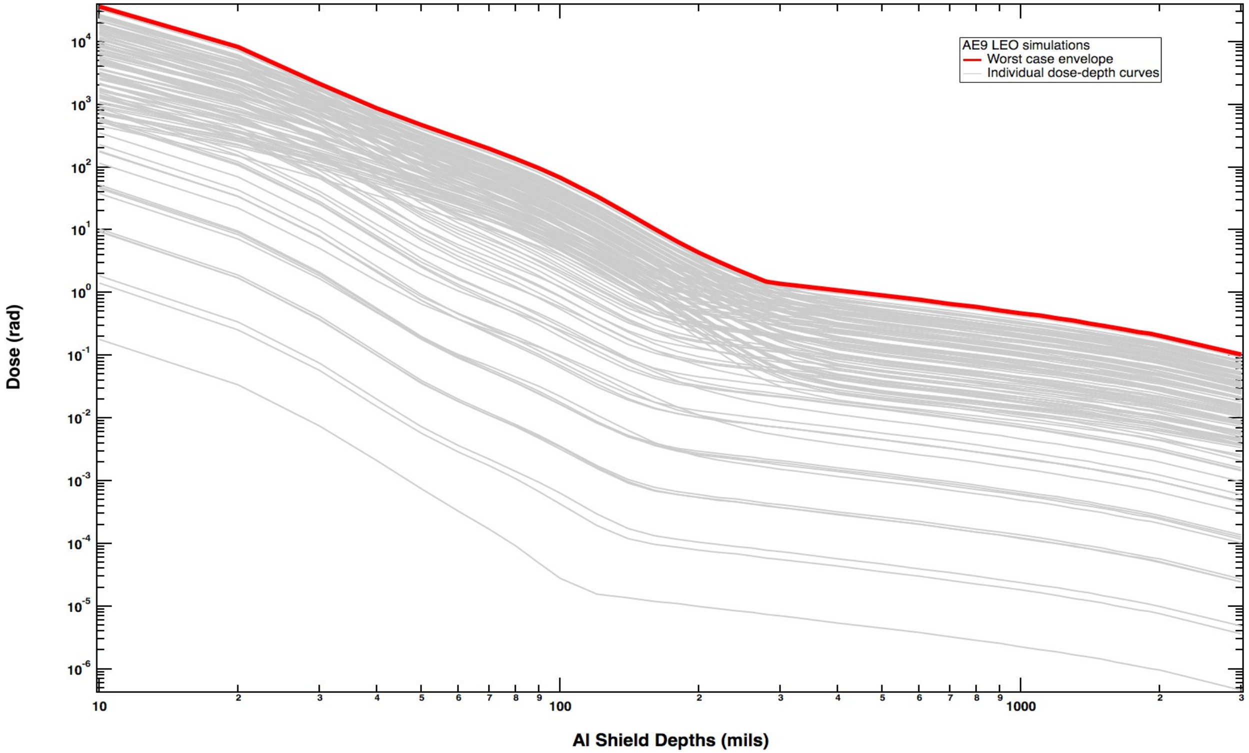
*Earth shown for scale only.

AE9 LEO Dose Calculations

Worst Orbits:

1500 km, 10º for 10-30, 300-3000 mils of Al shielding.

1500 km, 60º for 40-280 mils of Al shielding.



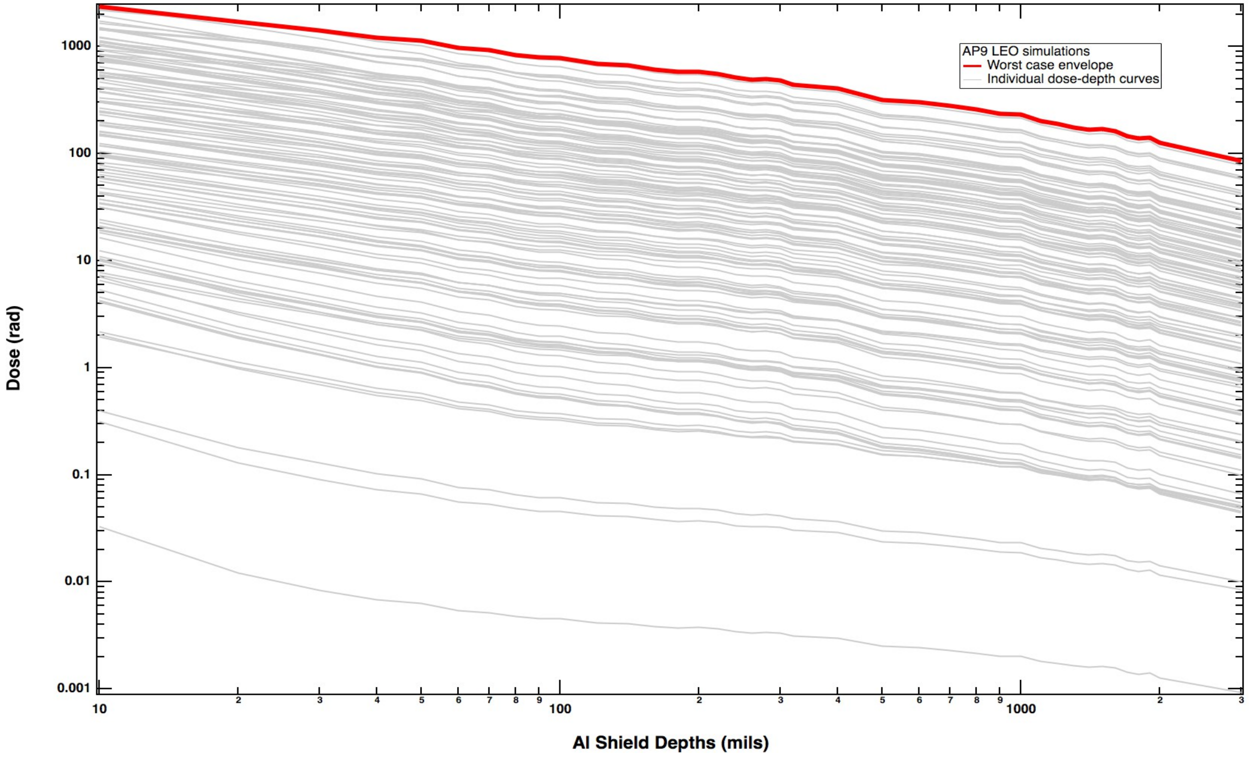
AP9 LEO Dose Calculations

Worst Orbits:

1500 km, 30º for 10 mils of Al shielding.

1500 km, 10º for 20 mils of Al shielding.

1500 km, 0º for 30-3000 mils of Al shielding.



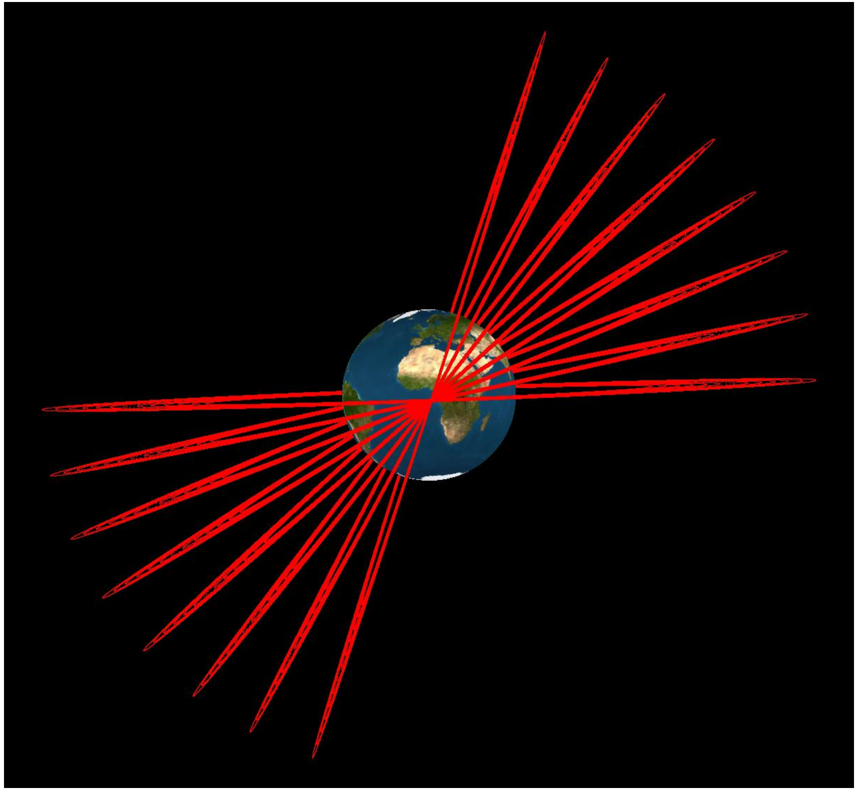
IRENE MEO Dose Calculations

Circular orbits

Altitudes: 10000-22000 km, 1000 km steps.

Inclinations: 0-70º, 10º steps.

Duration: 1 year, 300s steps.



*Earth shown for scale only.

AE9 MEO Dose Calculations

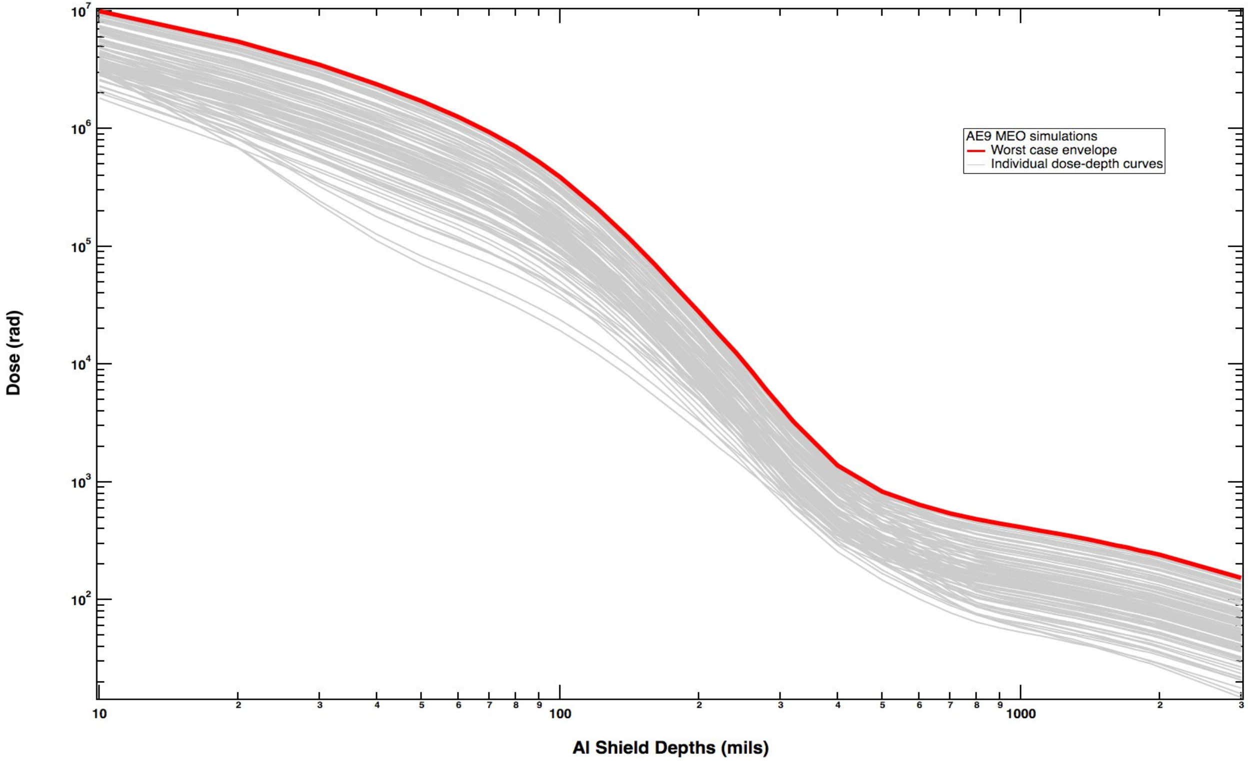
Worst Orbits:

21000 km, 0º for 10-30 mils of Al shielding.

20000 km, 0º for 40-70, 700-3000 mils of Al shielding.

19000 km, 0º for 80-120, 500-600 mils of Al shielding.

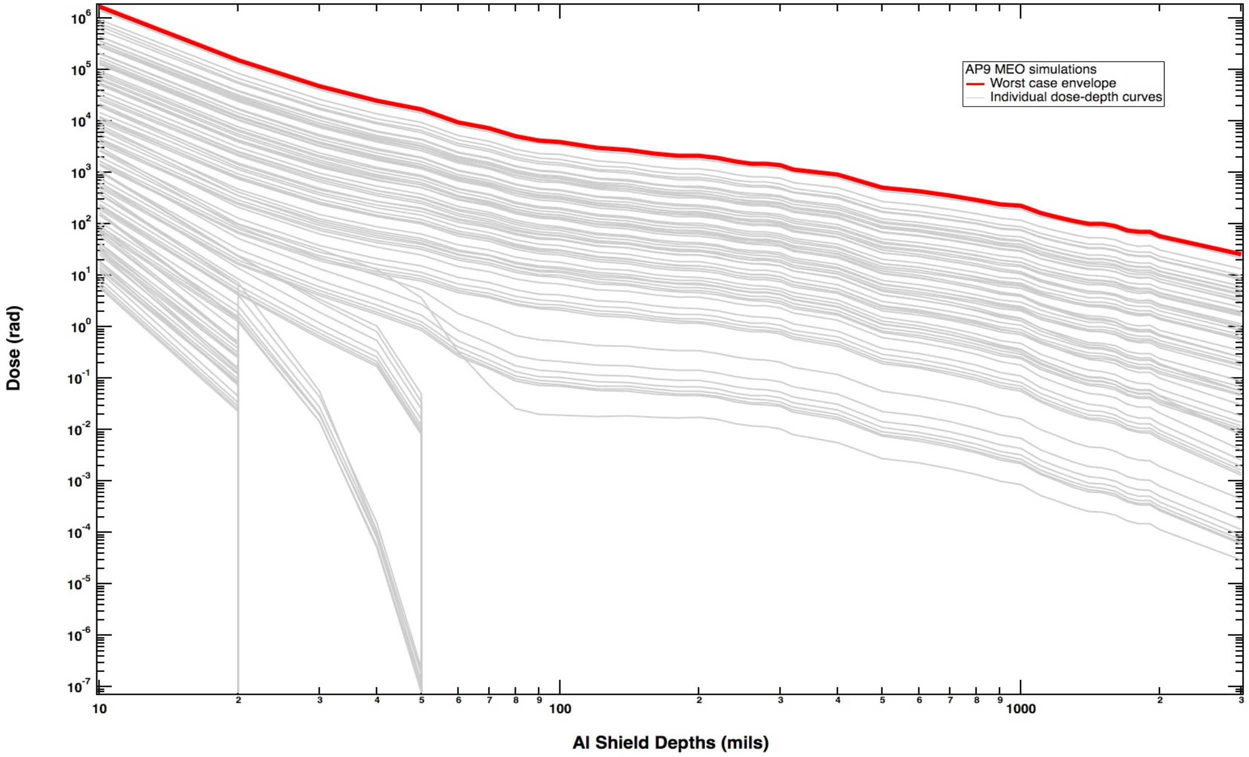
18000 km, 0º for 140-400 mils of Al shielding.



AP9 MEO Dose Calculations

Worst Orbit:

10000 km, 0º for all Al shield depths.



IRENE GEO Dose Calculations

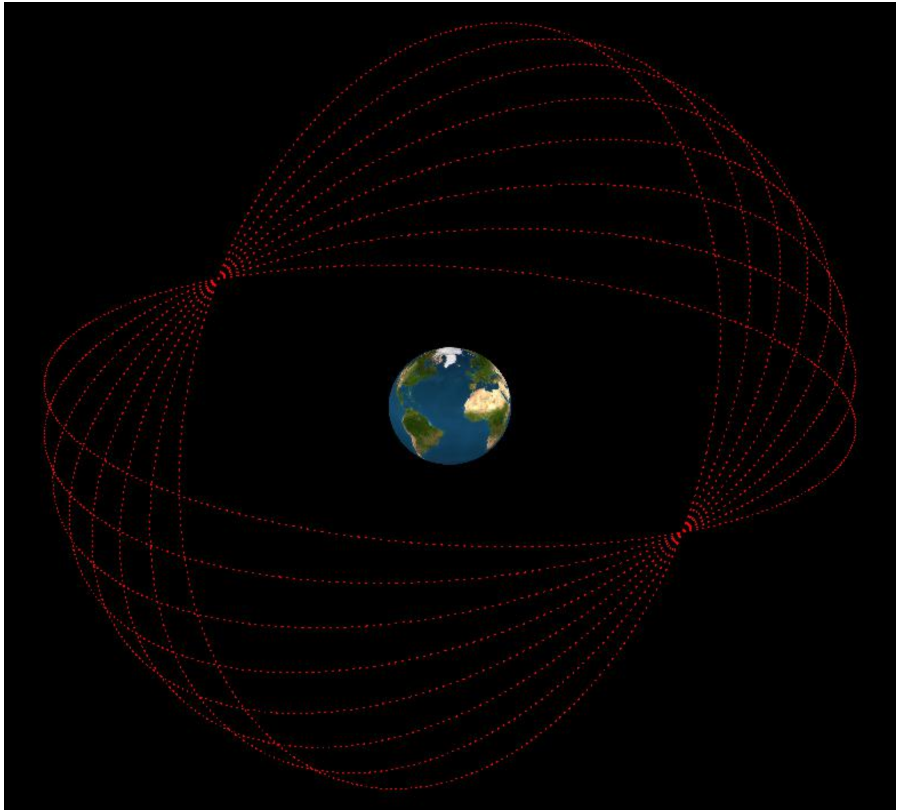
Circular orbits

Altitude: 35786 km

Longitude:0-330º, 30º steps and 160º (AE8/AP8 worst longitude) at 0º inclination.

Inclinations at worst longitude: 0-70º, 10º steps.

Duration: 1 year, 3600s steps.



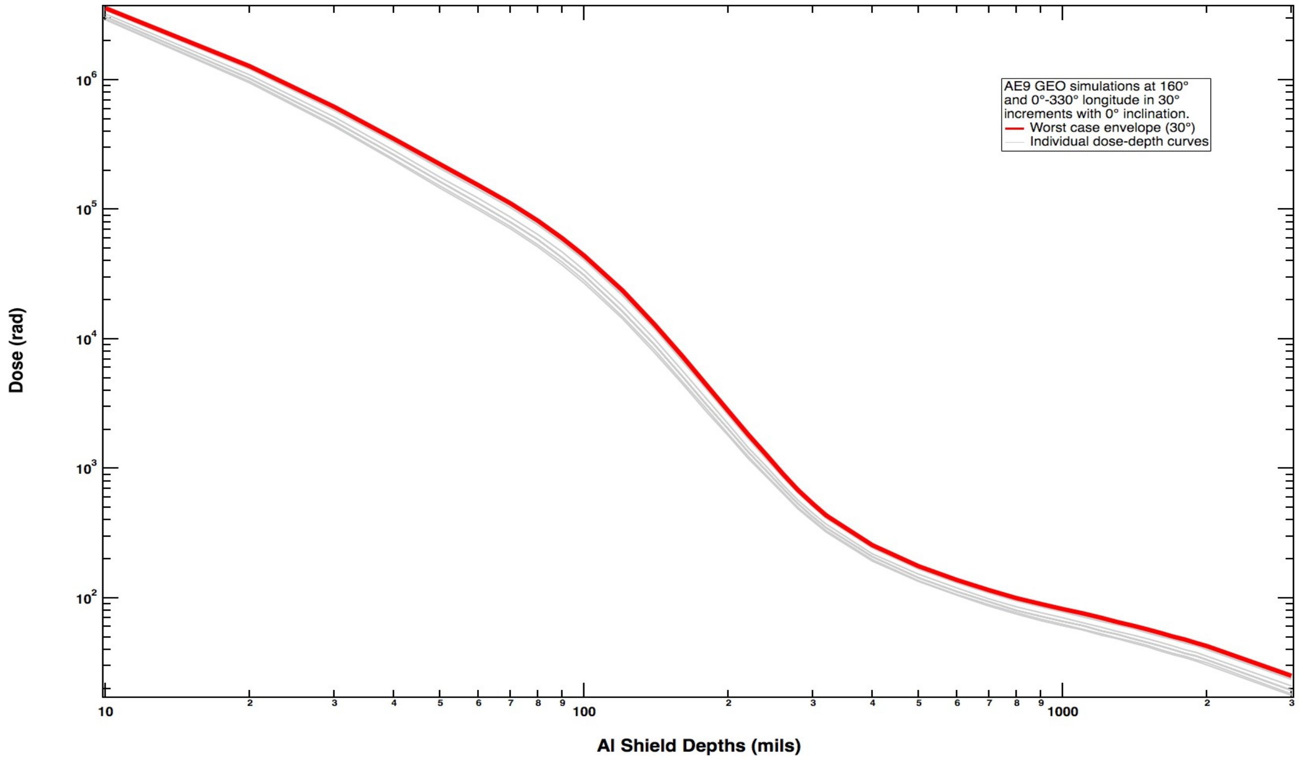
*Earth shown for scale only.

AE9 GEO Dose Calculations

Given that at GEO a satellite orbits with the rotation of the Earth, longitude must be considered.

Worst longitude at 0º inclination:

30º for all Al shield depths.



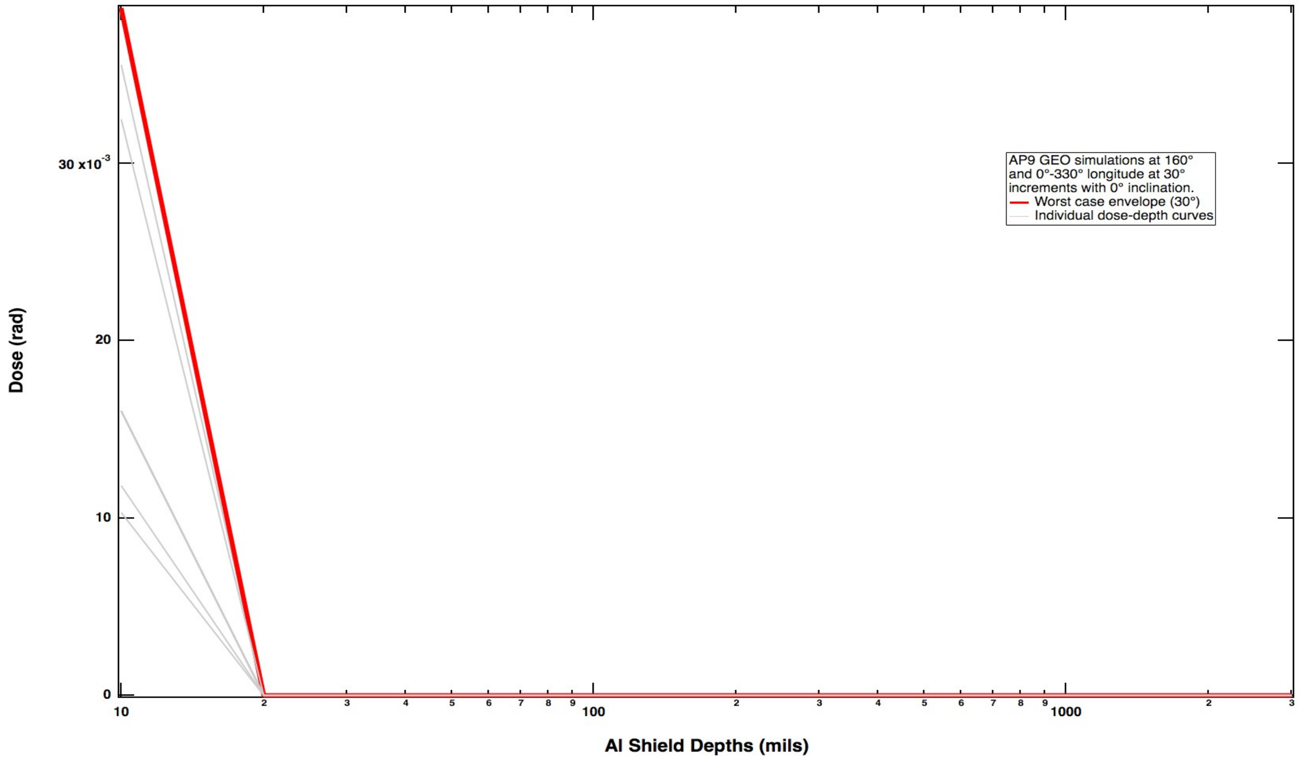
Informal Discussion Only for Planning Purpose

AP9 GEO Dose Calculations

Given that at GEO a satellite orbits with the rotation of the Earth, longitude must be considered.

Worst longitude at 0º inclination:

30º for all Al shield depths.

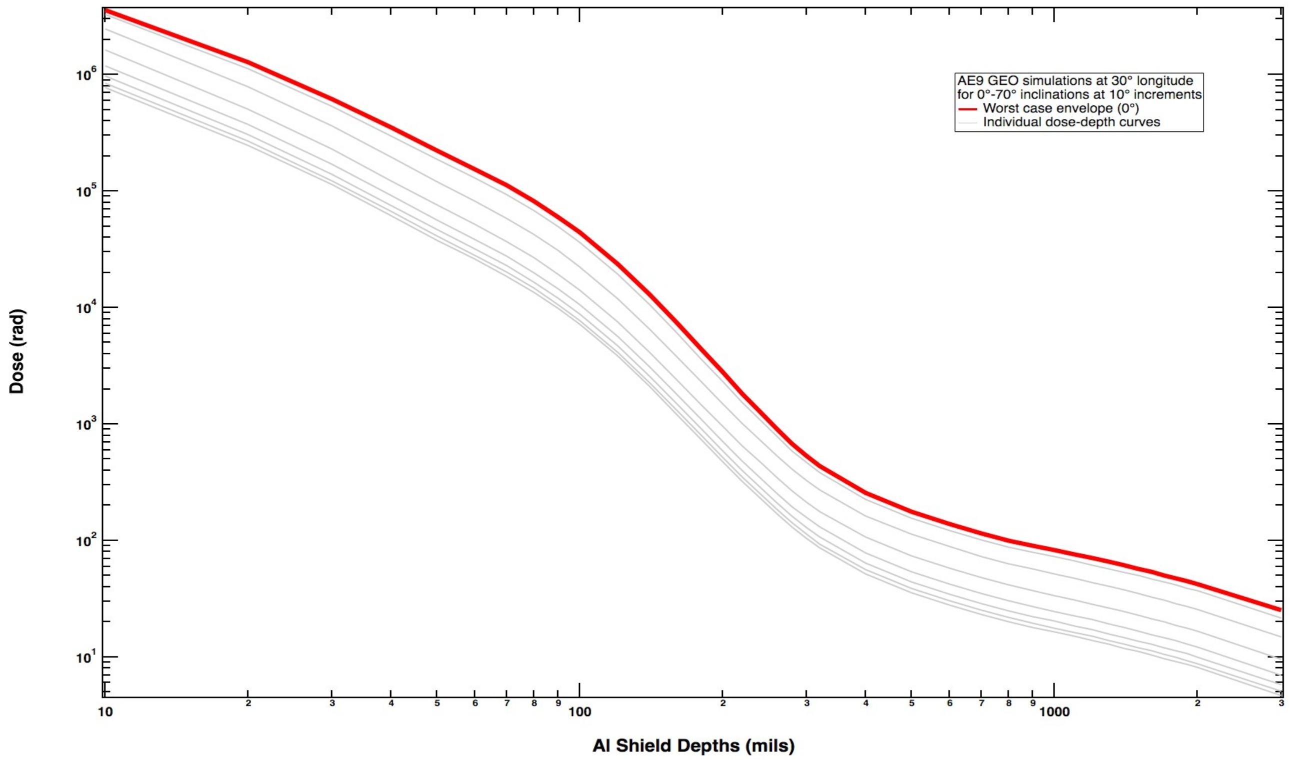


AE9 GEO Dose Calculations

At 30º longitude, dose-depth curves were calculated for inclinations from 0º-70º.

Worst Orbit:

0º inclination at 30º longitude for all Al shield depths.

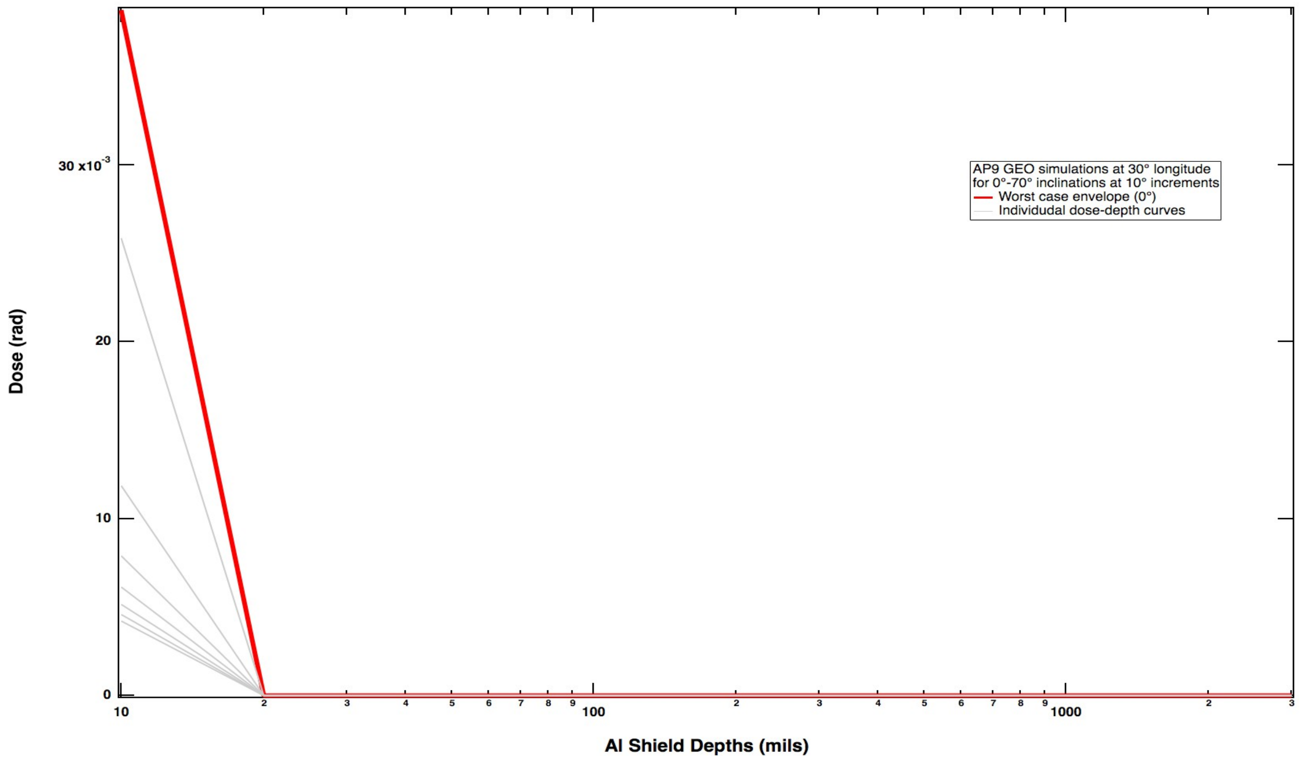


AP9 GEO Dose Calculations

At 30º longitude, dose-depth curves were calculated for inclinations from 0º-70º.

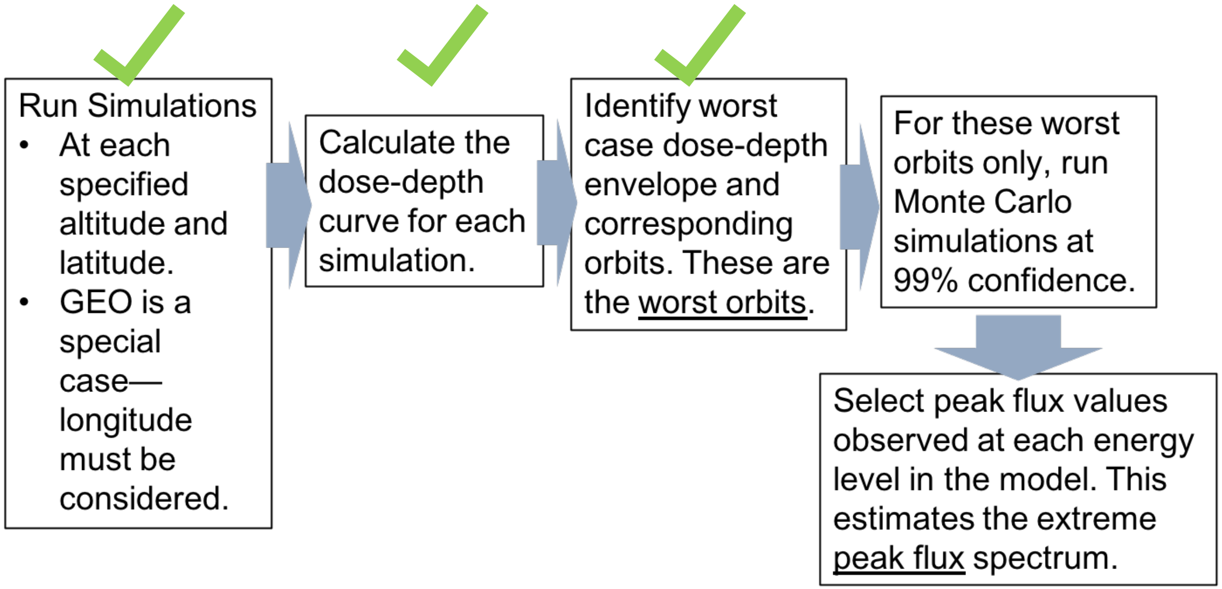
Worst Orbit:

0º inclination at 30º longitude for all Al shield depths.



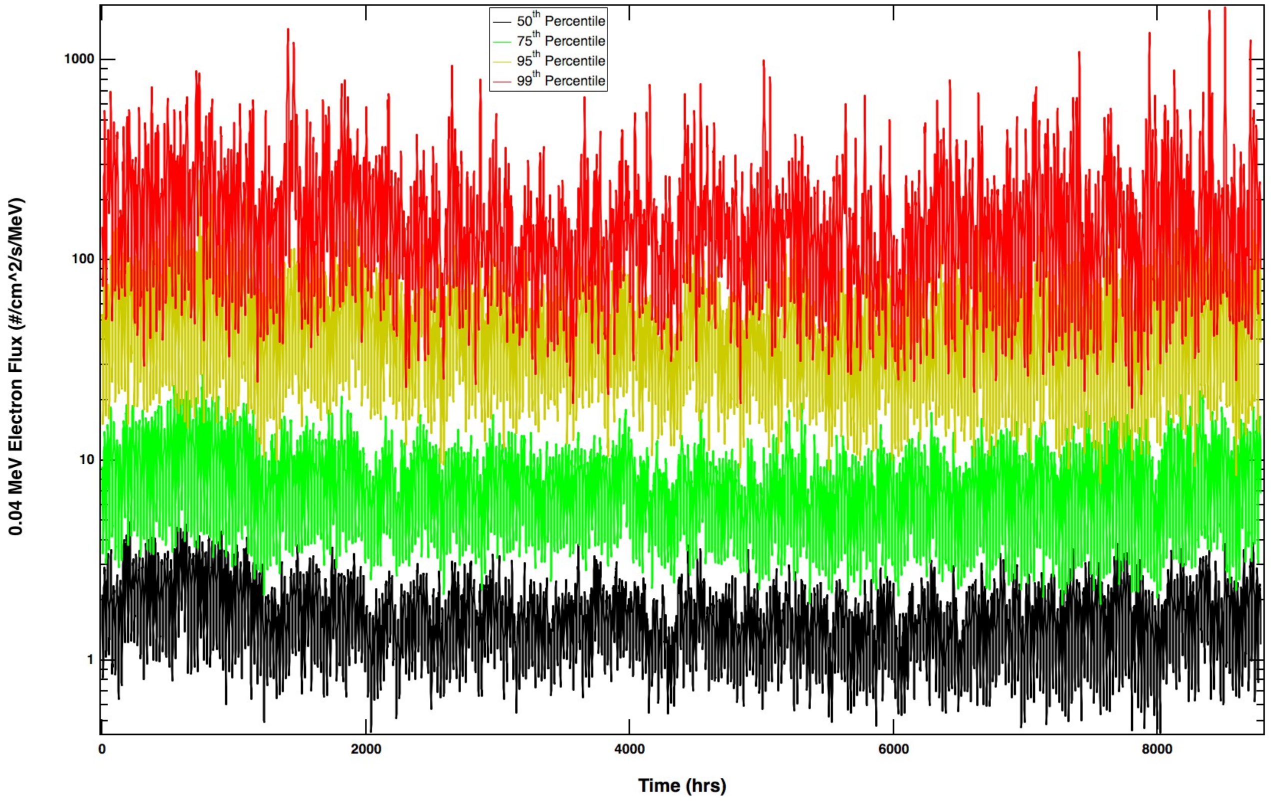
Monte Carlo Simulations

Having identified the worst GEO orbit for the mean environment, the next step was to run Monte Carlo IRENE runs for and identify the peak flux.



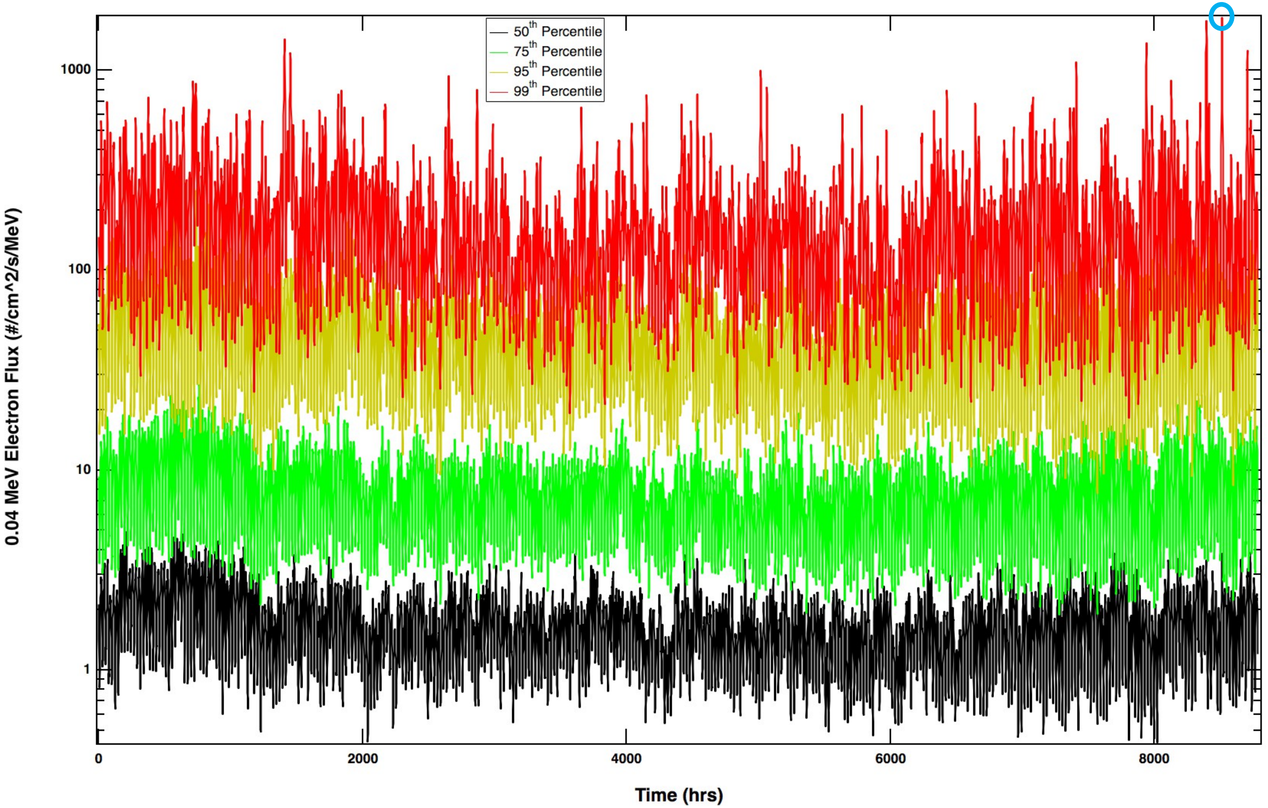
Monte Carlo Simulations

The IRENE Monte Carlo simulations consider environment variations and measurement uncertainties and produce fluxes for different energy levels at user-defined confidence levels.



Monte Carlo Simulations

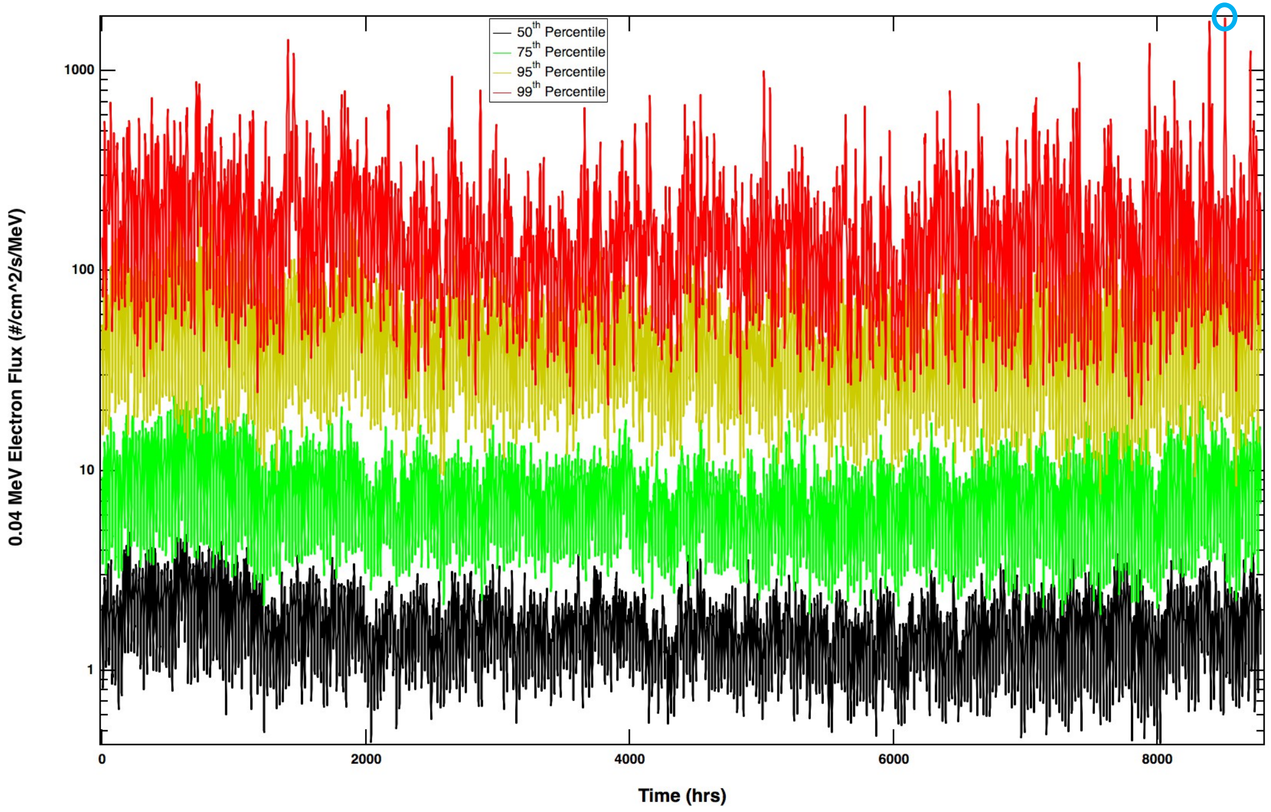
For each energy level considered in the model, IRENE outputs flux vs time at user-defined confidence levels. The figure to the right is an example of a simulation for a single energy level at 50, 75, 95, and 99 percent confidence.



Monte Carlo Simulations

The maximum value for the 99th percentile for each level was selected as a worst case flux for that energy level.

For multiple orbits in the worst case dose-depth envelope, at each energy level only the highest flux was selected.

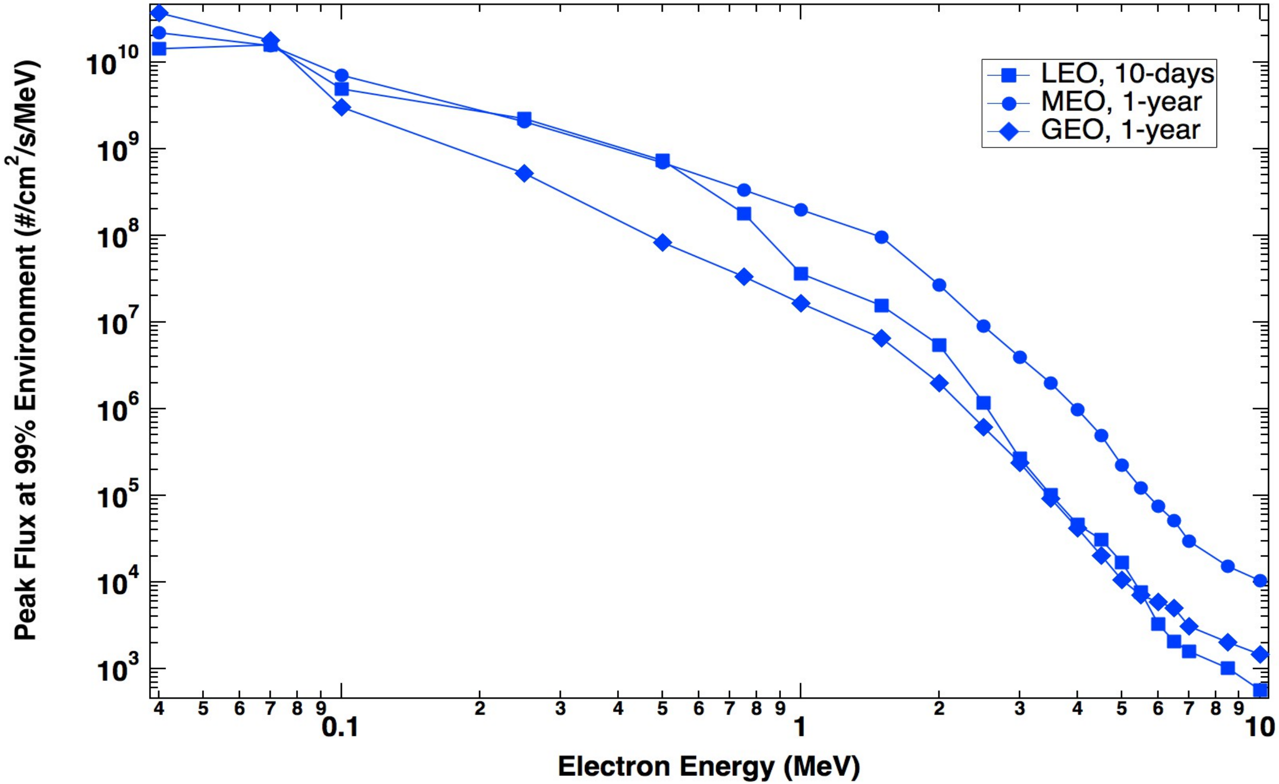


Informal Discussion Only for Planning Purpose

Peak Flux

Selecting the peak flux from the worst case envelopes at the 99% environment at each energy level results in an upper bound or worst case flux.

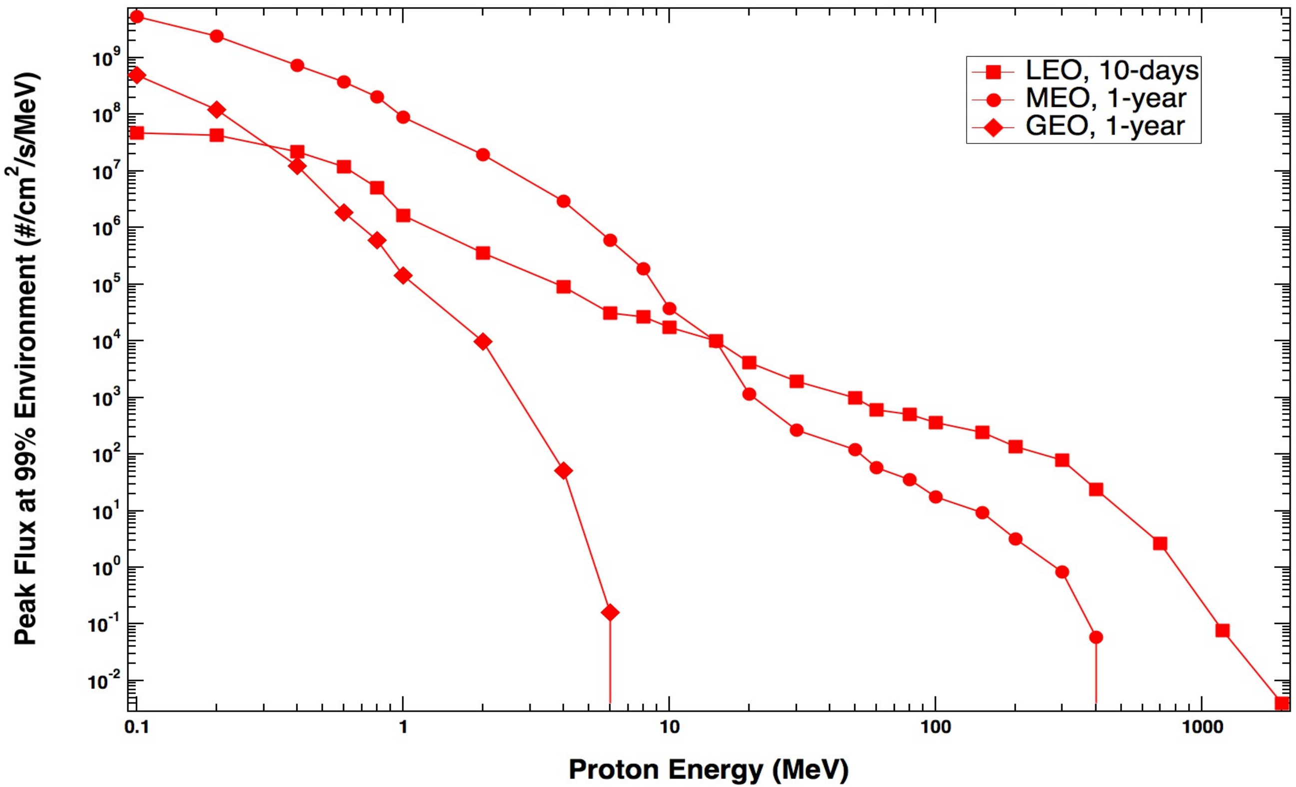
Peak Electron Flux at 99% Environment for Worst Orbits.



Peak Flux

Selecting the peak flux from the worst case envelopes at the 99% environment at each energy level results in an upper bound or worst case flux.

Peak Proton Flux at 99% Environment for Worst Orbits.



Summary

LEO	MEO	GEO
(Alt. [km], inclination [deg], AX9)	(Alt. [km], inclination [deg], AX9)	(Alt. [km], E longitude ([deg], inclination [deg], AX9)
(1500, 0, AP9) (1500, 10, AE9/AP9) (1500, 30, AP9) (1500, 60, AE9)	(10000, 0, AP9) (18000, 0, AE9) (19000, 0, AE9) (20000, 0, AE9) (21000, 0, AE9)	(35786, 30, 0, AE9/AP9)

99% confidence peak electron and proton flux spectra have been calculated using these orbits.

Summary

Run Simulations

- At each specified altitude and latitude.
- GEO is a special case—longitude must be considered.

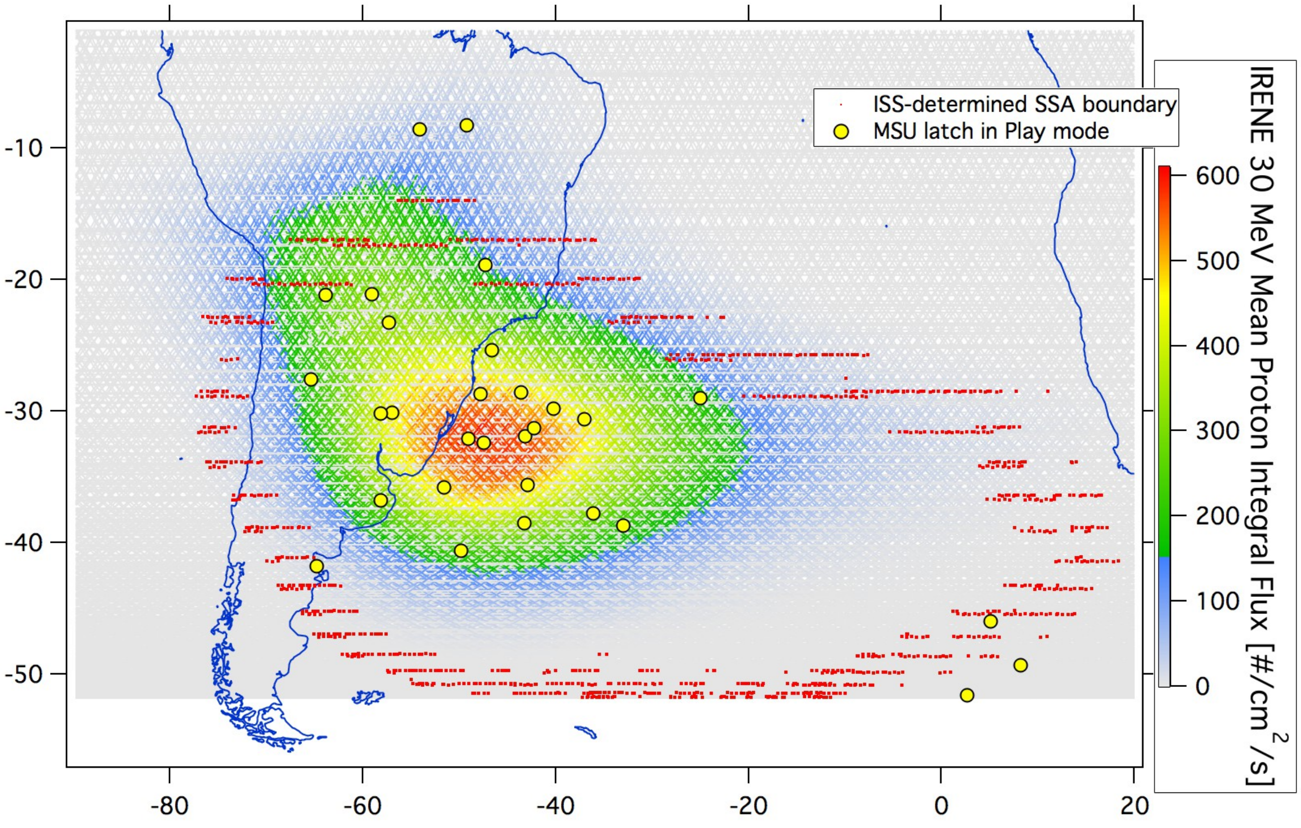
Calculate the dose-depth curve for each simulation.

Identify worst case dose-depth envelope and corresponding orbits. These are the <u>worst orbits</u>.

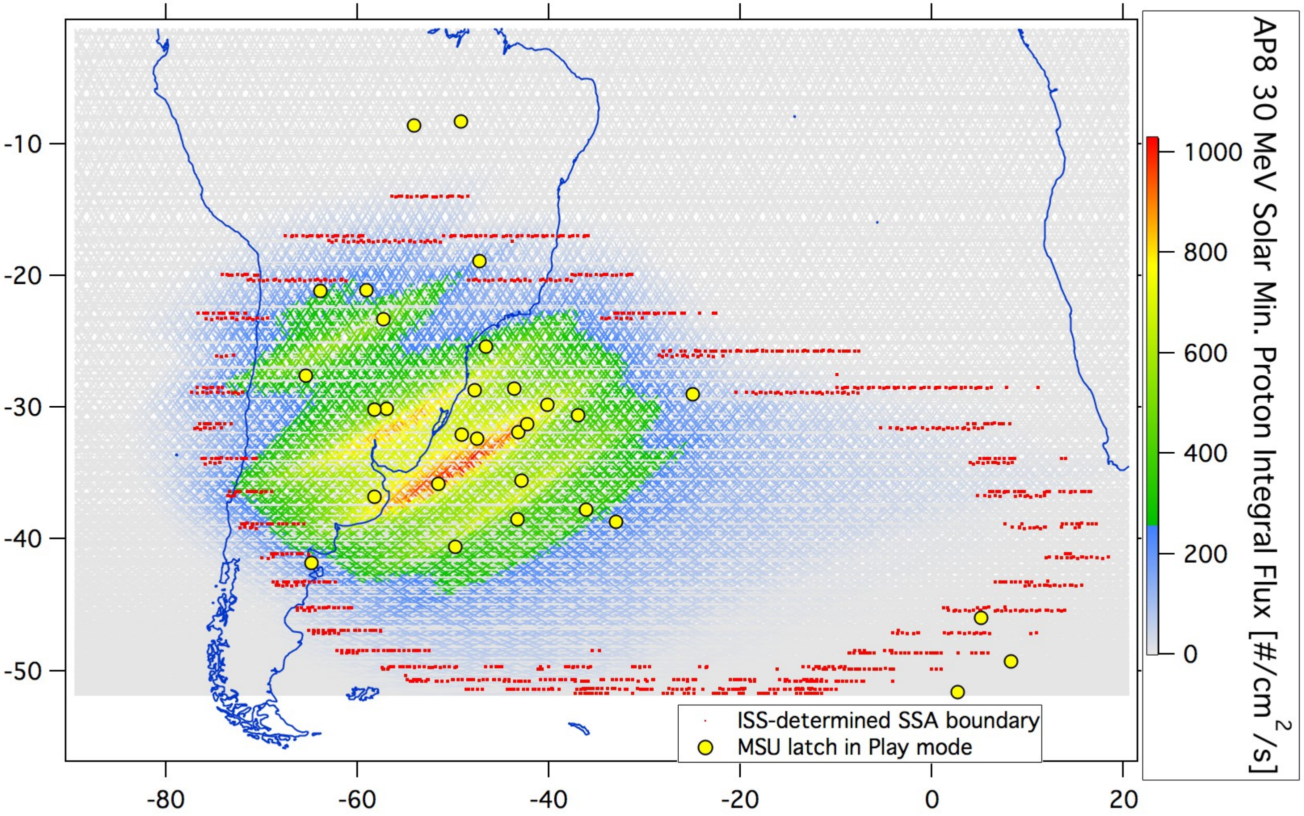
For these worst orbits only, run Monte Carlo simulations at 99% confidence.

Select peak flux values observed at each energy level in the model. This estimates the extreme <u>peak flux</u> spectrum.

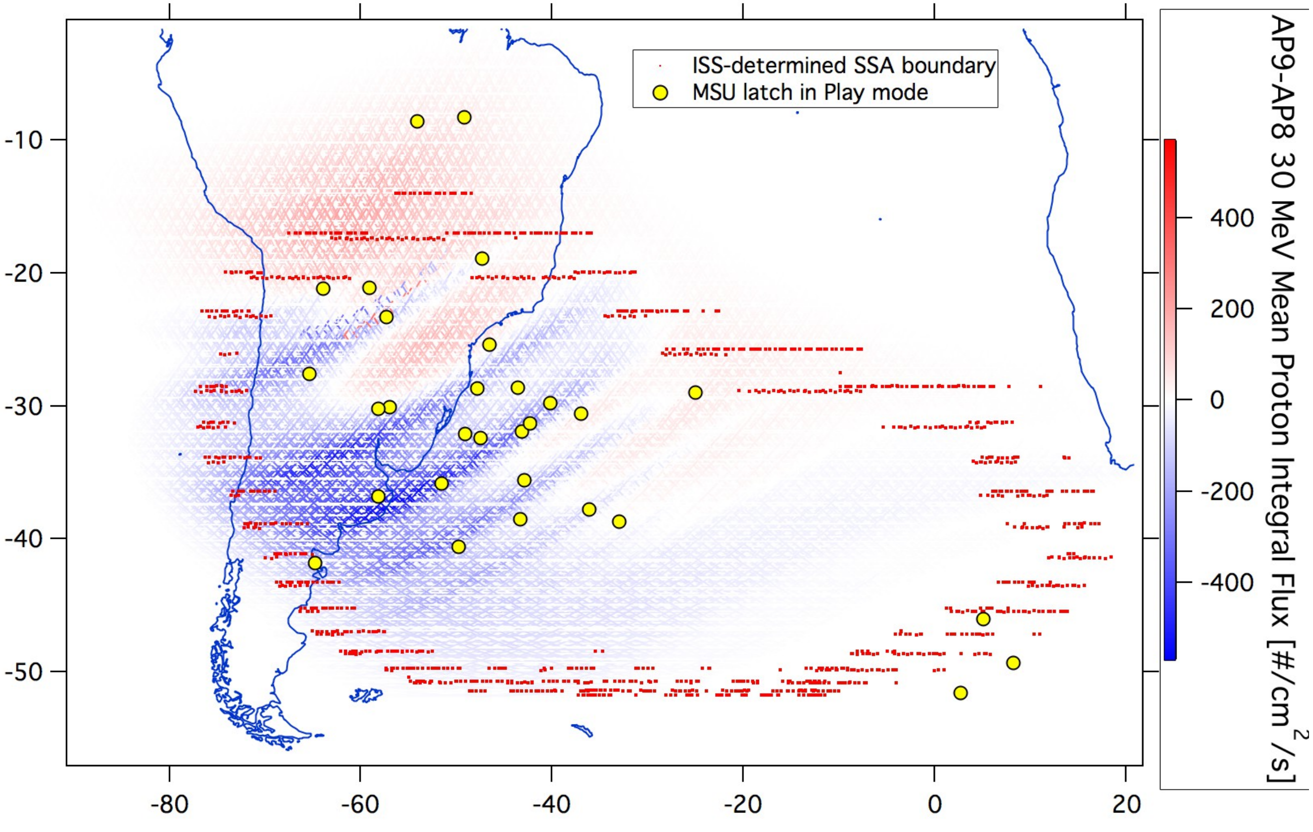
South Atlantic Anomaly at ISS Altitude: AP9



South Atlantic Anomaly at ISS Altitude: AP8



South Atlantic Anomaly at ISS Altitude: AP9-AP8



Backup

IRENE Task

Determine worst circular orbits as predicted by the IRENE software package over 1, 3, 5, and 7 years.

- Is there a difference between years in the IRENE models, and if so, is the year-to-year variation significant?

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Expected Output

Worst case orbit and fluence numbers for each of the radiation environment components listed below

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Environment Input	**Models**	**Notes**
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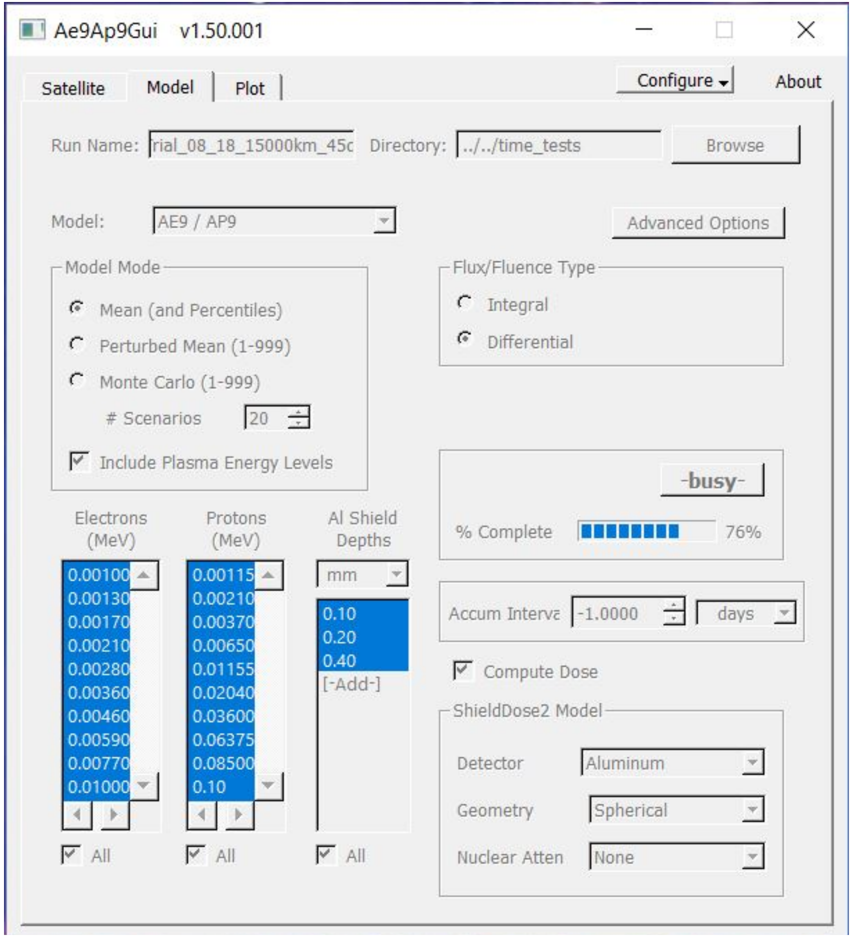
Characterization Plan

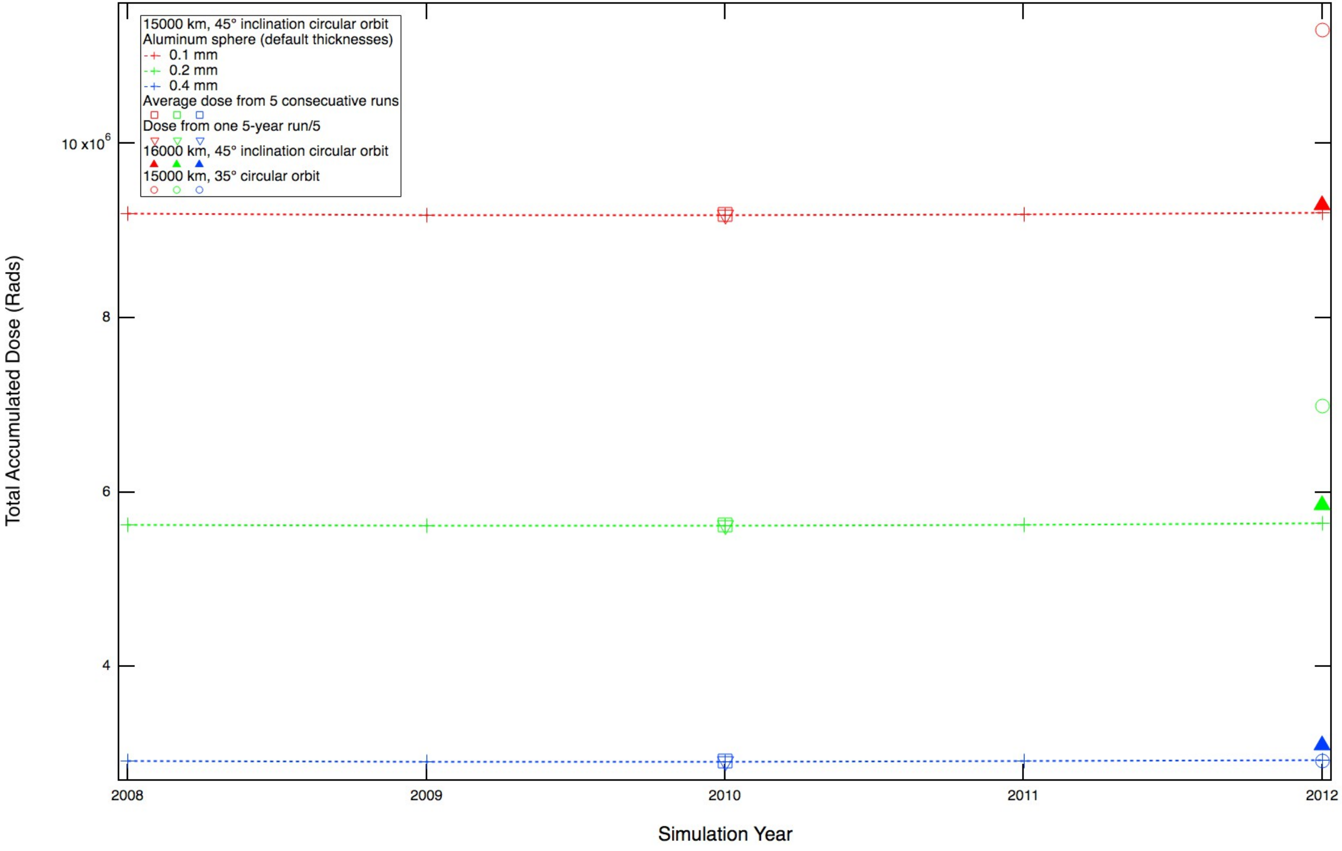
Simulate five consecutive years using the same input parameters and compare relevant results to a full five-year simulation.

- Fluence
  - Plasma protons/electrons
  - Trapped protons/electrons
- Dose

According to software documentation, temporal solar cycle effects are not included in the model.



Example: Dose



Small variations from year to year (<1%)

The maximum difference between 5x any one year fluence and the corresponding five-year equivalent is <0.03%.

The minimum difference from the mean and one altitude step difference is 1%.

The minimum difference from one inclination step is ~23%.

IRENE Task

Determine worst circular orbits as predicted by the IRENE software package over 1, 3, 5, and 7 years.

- It was shown that year-to-year variations were small compared to variations in the average environment from changing spatial orbit parameters for LEO, MEO, and GEO. Therefore 1-year runs were deemed sufficient.
- Seasonal variations might be expected for runs shorter than a year. For LEO, the short recommended time step meant that it would take months to get through the LEO orbits. Temporal dependence was investigated further for LEO and variations of ~4% or less were observed in results from month-to month and were small compared to changing inclination or altitude. 10-day runs at each altitude and inclination were performed.

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