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# **IRENE: AE9/AP9/SPM Radiation Environment Model**

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## **Software Verification Testing**

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V1. 50.001

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Approved for public release; distribution is unlimited.

The IRENE (International Radiation Environment Near Earth): (AE9/AP9/SPM) model was developed by the Air Force Research Laboratory in partnership with MIT Lincoln Laboratory, Aerospace Corporation, Atmospheric and Environmental Research, Incorporated, Los Alamos National Laboratory and Boston College Institute for Scientific Research.

IRENE (AE9/AP9/SPM) development team: Wm. Robert Johnston<sup>1</sup> (PI), T. Paul O'Brien<sup>2</sup> (PI), Gregory Ginnet<sup>3</sup> (PI), Stuart Huston<sup>4</sup>, Tim Guild<sup>2</sup>, Christopher Roth<sup>4</sup>, Yi-Jiun Su<sup>1</sup>, Rick Quinn<sup>4</sup>, Michael Starks<sup>1</sup>, Paul Whelan<sup>4</sup>, Reiner Friedel<sup>5</sup>, Chad Lindstrom<sup>1</sup>, Steve Morley<sup>5</sup>, and Dan Madden<sup>6</sup>.

To contact the IRENE (AE9/AP9/SPM) development team, email [ae9ap9@vdl.afrl.af.mil](mailto:ae9ap9@vdl.afrl.af.mil) .

The IRENE (AE9/AP9/SPM) model and related information can be obtained from AFRL's Virtual Distributed Laboratory (VDL) website: <https://www.vdl.afrl.af.mil/programs/ae9ap9>

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Document Authors: T. Paul O'Brien/Aerospace, Christopher Roth/AER, Lisa Winter/AER

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<sup>1</sup> Air Force Research Laboratory, Space Vehicles Directorate

<sup>2</sup> Aerospace Corporation

<sup>3</sup> MIT Lincoln Laboratory

<sup>4</sup> Atmospheric and Environmental Research, Incorporated

<sup>5</sup> Los Alamos National Laboratory

<sup>6</sup> Boston College Institute for Scientific Research

## **Introduction**

This document describes the verification testing results for the IRENE: AE9/AP9/SPM v1.50.001 model software release. The changes contained in the v1.50.001 release are primarily in its model database updates, with some C++ coding bugfixes and enhancements.

The AE9, AP9 and SPM model results generated by the C++ software were compared against those from the Matlab-based prototype. The ‘Legacy’ model results of this release were compared to those from the previous release. The parallelized Ax9 C++ model run results were compared to those from single-threaded runs. Tests were performed to verify the stability of long-term Monte Carlo computations. The operation of GUI application, its model run invocation, outputs produced and the values plotted, were tested for consistency with the selections and specifications made in the user interface.

### **AE9/AP9 Matlab prototype versus AE9/AP9 C++ code**

The AE9/AP9 v1.50.001 C++ software was compared to the Matlab prototype in a head-to-head fashion to identify any discrepancies. (Matlab is a registered trademark of the The MathWorks Inc.). Both programs were used to generate comparable ASCII output files. These files were then compared to determine whether the two implementations gave sufficiently similar answers. The nominal purpose of the testing was to verify that the C++ implementation matches the Matlab implementation. However, in some cases the C++ implementation was found to be superior and the Matlab implementation was modified to match the C++. This section summarizes the scope of the head-to-head testing, explains the level of agreement, and documents a few discrepancies that were deemed acceptable (i.e., they did not lead to a revision of the C++ or Matlab implementations).

The Matlab prototype and C++ are almost entirely separate implementations of the AE9/AP9 algorithms. They do, however, share a common low-level library that evaluates the Olson-Pfizer Quiet magnetic field model and traces field lines in that model. This functionality is usually referred to as the “fastI” calculation.

The head-to-head testing covers about 130 features through 18 separate tests. These tests are summarized in Appendix A. Each feature corresponds to one option or a unique combination of options in the ASCII input files used to drive the AE9/AP9 command line utility. A Matlab program was built to read these ASCII inputs and perform the same functions as the command line utility (the C++ implementation). Each of the 18 tests includes the command line input file for one or more models (AE9, AP9, SPME, SPMH, SPMHE, or SPMO) as well as any support files for, e.g., ephemeris or directions of interest. These test files and the expected outputs generated by the Matlab prototype are provided via the AE9/AP9 team code repository in a “formal\_tests” folder. Matlab driver scripts run each of the tests and compare their outputs.

The comparison script reports when a file is missing from either the C++ or Matlab set, and whether any numbers within those files are larger than allowed by a set of acceptance rules.

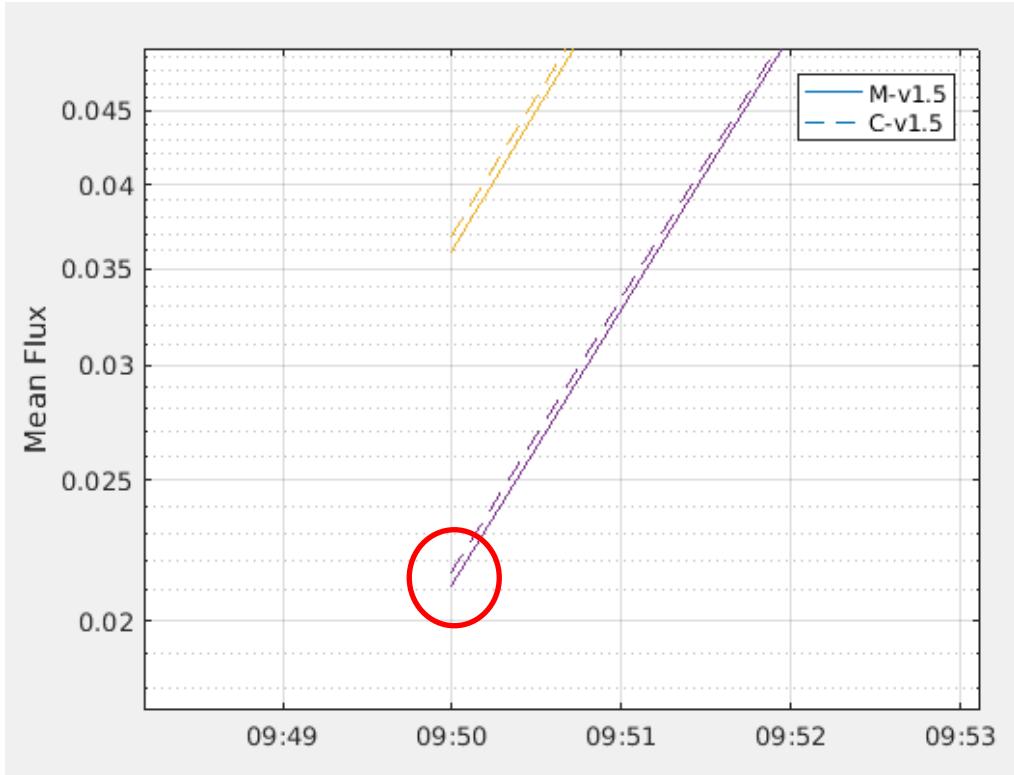
The acceptance rules applied to all output files are as follows:

- For *dates*, the date value is converted to a date serial, and the difference between the C++ and Matlab dates is computed. If that difference exceeds 0.5 seconds, a discrepancy is reported.
- For ephemeris *positions*, the coordinates are converted to an inertial system, and then the distance between the C++ and Matlab positions is computed. This distance is allowed to be up to 1% of the radial distance from the center of the Earth, otherwise a discrepancy is reported.
- For *adiabatic coordinates*, the natural log of the ratio of the C++ and Matlab coordinates is computed, after adding 0.01 to each value. This 0.01 addition accounts for fixed precision ASCII output. If the log of the ratio exceeds 3%, a discrepancy is reported.
- For *dose and dose rate* numerical values, the natural log of the ratio of the C++ and Matlab values is taken after  $2 \times 10^{-5}$  is added to each value. If the log of the ratio exceeds 15%, a discrepancy is reported.
- For *all other* numerical values, the natural log of the ratio of the C++ and Matlab values is taken after  $2 \times 10^{-5}$  is added to each value. If the log of the ratio exceeds 1%, a discrepancy is reported.

These allowances were determined through the course of testing as different aspects of the Matlab and C++ codes were compared. When many seemingly acceptable discrepancies were reported by the comparison script, the allowances were modified to accommodate larger or different kinds of discrepancies for specific types of outputs. Aside from these allowances two additional special case discrepancies were deemed acceptable: the KEPLER\_RV\_LI test and the GPS\_1DAY\_SPMO test.

*The KEPLER\_RV\_LI acceptable fail discrepancy:*

The KEPLER\_RV\_LI test determines how well the Kepler propagators agree between the two implementations, given an initial time, location, and velocity. The test propagates the orbit for 1 day and evaluates AE9 along the orbit, computing mean flux and fluence as well as accumulated dose. The test fails on mean\_flux (a time series comparison) due to a single point near a very sharp temporal gradient where the C++ and Matlab versions disagree by about 3%. The gradient very steep over a 5 minute time step. Given that the Kepler-RV orbit propagators differ by up to 3-4 km in this case, we must expect sometimes steep gradients will not exactly match between the two implementations. The KEPLER\_RV\_LI passes all other comparisons (mean\_dosecccumFull, mean\_fluenceFull, mean\_fluxFullAvg, and orbit). The figures below highlights the single point that exceeds the regular discrepancy allowances.



*Figure 1. An acceptable discrepancy in the KEPLER\_RV\_LI test. The horizontal axis is time, and the vertical axis is mean electron differential flux. Each color is a different energy channel. The Matlab implementation is compared to the C++ implementation. The difference in mean flux between the C++ and Matlab versions is about 3% at the circled point. This discrepancy can be explained by a very sharp spatial gradient and a very slight (few km) difference in the computed locations for the two implementations of the Kepler propagator.*

#### *The GPS\_1\_DAY\_SPMO acceptable fail discrepancy:*

The GPS\_1DAY\_SPMO test evaluates the SPMO model along the GPS orbit for 1 day. The test fails on a mean flux discrepancy. This test passes when a uniform time step is used. However, when the non-uniform time step was added, it fails. This test also samples multiple pitch angles. The fail is with a maximum error of 1.2%, and one cannot visually see the failure on a plot. This fail is acceptable because it is a very small discrepancy, although larger than the 1% allowance deemed acceptable for other tests.

### **AE9/AP9 C++ code, v1.50.001 versus v1.35.001**

Where feasible, the results produced by the AE9/AP9 v1.50.001 C++ software were compared to those from other versions, to ensure their consistency.

For the v1.50.001 release, the database files for the AE9 and AP9 models were revised with the addition of several new satellite datasets, the perturbation algorithm used for the AE9, AP9 and the SPM models, and the calculation method for the dose accumulation was modified. For these reasons, these new model results cannot be compared to that of its previous release, as many differences are expected. However, the full set of AE9, AP9 and SPM model results were verified to be consistent with their Matlab-based prototype implementation (as described in a previous section of this document).

This IRENE software suite also includes the capability to produce flux and fluence values from several ‘Legacy’ radiation belt models, namely AE8, AP8, CRRESELE, CRRESPRO and CAMMICE. For these models, all the comparisons showed *identical* results between the two versions. This was expected, as there were no changes in the Legacy model algorithms or their associated database files.

## **AE9/AP9 C++ code, v1.50.001 single-threaded versus multi-threaded**

The results produced by the AE9/AP9 v1.50.001 C++ software were compared to itself when parallelized, to ensure consistency.

The software release features the capability to parallelize the various calculations for the AE9, AP9 and SPM models. Additional verification tests were performed to ensure that model calculation results when using a single processor matched those using multiple processors. A model run was defined to calculate the orbit ephemeris (propagated from a Van Allen Probe TLE), flux (for both protons and electrons), associated fluence and dose rates and accumulations, and their aggregation statistics. The percentage differences between the results from the two runs were calculated by dividing the difference of the two values by the first value, and then multiplied by 100. The maximum percentage difference observed when comparing these results produced by a single processor run vs a 16-processor run was  $5 \times 10^{-4}\%$ . Further scrutiny revealed this slight difference originated from the ephemeris computations using 16 processors, when the time period is broken up into multiple segments, each with a calculated offset start time. Even when using a ‘double’ floating-point variable for the Modified Julian Date time value, the accuracy is limited to  $\sim 1 \times 10^{-5}$  seconds. This slight inaccuracy in time leads to slight shifts in the generated ephemeris position, on the order of 1 cm or less. These slight positional differences produce slight differences in the associated adiabatic coordinates. Depending on the steepness of the local gradients of the flux maps for the models, a slight coordinate difference may generate a slightly larger difference in the resulting flux value. A follow-up 16-processor model run was performed, except using the orbit ephemeris that was generated by a single processor. The comparison for these results to those from the single-processor model run showed that they produced *identical* results.

Summary of Single- vs Multi-threaded Comparison of v1.50.001, Percentage Difference of Values, AE9

Model Results	Min	Max	5 <sup>th</sup> %	Median	95 <sup>th</sup> %	Std Dev	Remarks
AE9 Flux MC scenario #183	-2.198e-05	5.662e-04	0.000e+00	0.000e+00	0.000e+00	1.113e-05	
AE9 Flux Conf Level 95%	-2.212e-05	5.663e-04	0.000e+00	0.000e+00	0.000e+00	1.113e-05	
AE9 Fluence Intv Conf Level 50%	0.000e+00	3.132e-07	0.000e+00	0.000e+00	0.000e+00	4.428e-08	
AE9 Dose Accum Intv Conf Level 75%	0.000e+00	0.000e+00	0.000e+00	0.000e+00	0.000e+00	0.000e+00	
AE9 Dose Rate Intv MC scenario #105	0.000e+00	0.000e+00	0.000e+00	0.000e+00	0.000e+00	0.000e+00	
AE9 Flux Intv Avg MC scenario #25	-7.482e-07	4.397e-07	0.000e+00	0.000e+00	1.642e-07	1.083e-07	

Summary of Single- vs Multi-threaded Comparison of v1.50.001, Percentage Difference of Values, AP9

Model Results	Min	Max	5 <sup>th</sup> %	Median	95 <sup>th</sup> %	Std Dev	Remarks
AP9 Flux MC scenario #183	-2.206e-05	5.667e-04	0.000e+00	0.000e+00	0.000e+00	1.113e-05	
AP9 Flux Conf Level 95%	-2.202e-05	5.667e-04	0.000e+00	0.000e+00	0.000e+00	1.113e-05	
AP9 Fluence Intv Conf Level 50%	-9.550e-07	8.467e-07	-3.002e-07	0.000e+00	3.221e-07	2.030e-07	
AP9 Dose Accum Intv Conf Level 75%	0.000e+00	5.017e-06	0.000e+00	0.000e+00	0.000e+00	7.094e-07	
AP9 Dose Rate Intv MCscenario #105	-8.235e-06	0.000e+00	0.000e+00	0.000e+00	0.000e+00	1.164e-06	
AP9 Flux Intv Avg MC scenario #25	-9.782e-07	8.975e-07	-1.280e-07	0.000e+00	4.602e-07	1.980e-07	

Summary of Single- vs Multi-threaded Comparison of v1.50.001, Percentage Difference of Values, using orbit ephemeris information generated by single-threaded application

Model Results	Min	Max	5 <sup>th</sup> %	Median	95 <sup>th</sup> %	Std Dev	Remarks
< all rows shown in previous tables>	0.000e+00	0.000e+00	0.000e+00	0.000e+00	0.000e+00	0.000e+00	single-threaded ephemeris used

Summary of Single- vs Multi-threaded Comparison of v1.50.001, Percentage Difference of Values in the Ephemeris Coordinates only, for a Van Allen Probe orbit.

Ephemeris Coord System	Min	Max	5 <sup>th</sup> %	Median	95 <sup>th</sup> %	Std Dev	Remarks
GDZ (lat, lon, alt km)	-1.245e-06	1.135e-06	0.000e+00	0.000e+00	0.000e+00	4.203e-08	Lat and lon in degrees
GEI (XYZ km)	-3.706e-06	2.876e-05	-1.240e-08	0.000e+00	1.185e-08	5.942e-07	
GEI (XYZ Re)	-3.271e-06	2.280e-05	0.000e+00	0.000e+00	0.000e+00	4.476e-07	

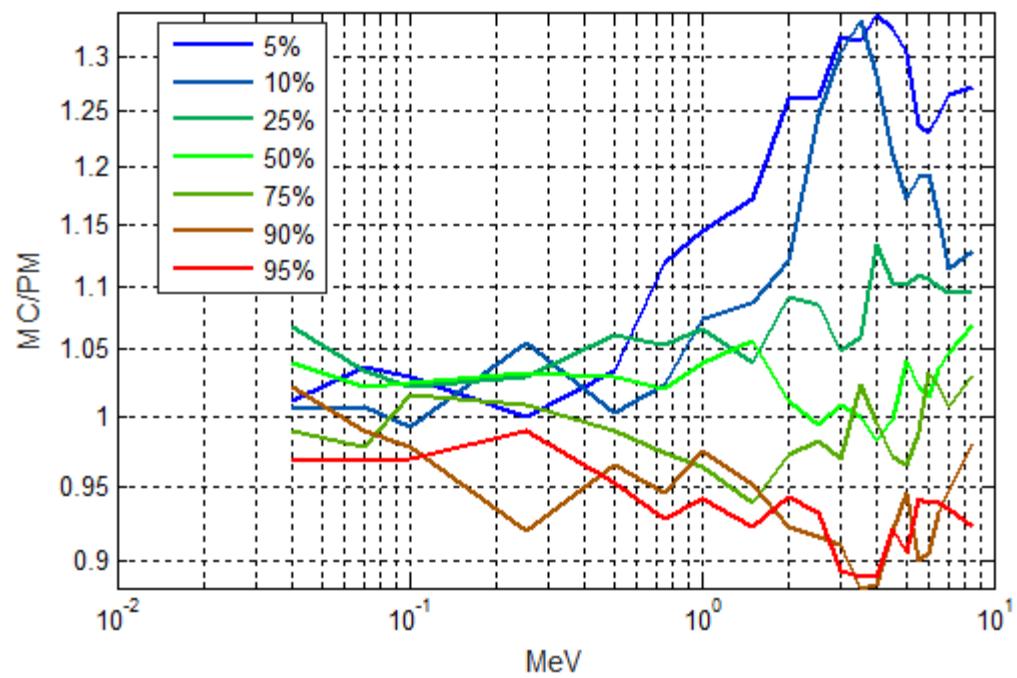
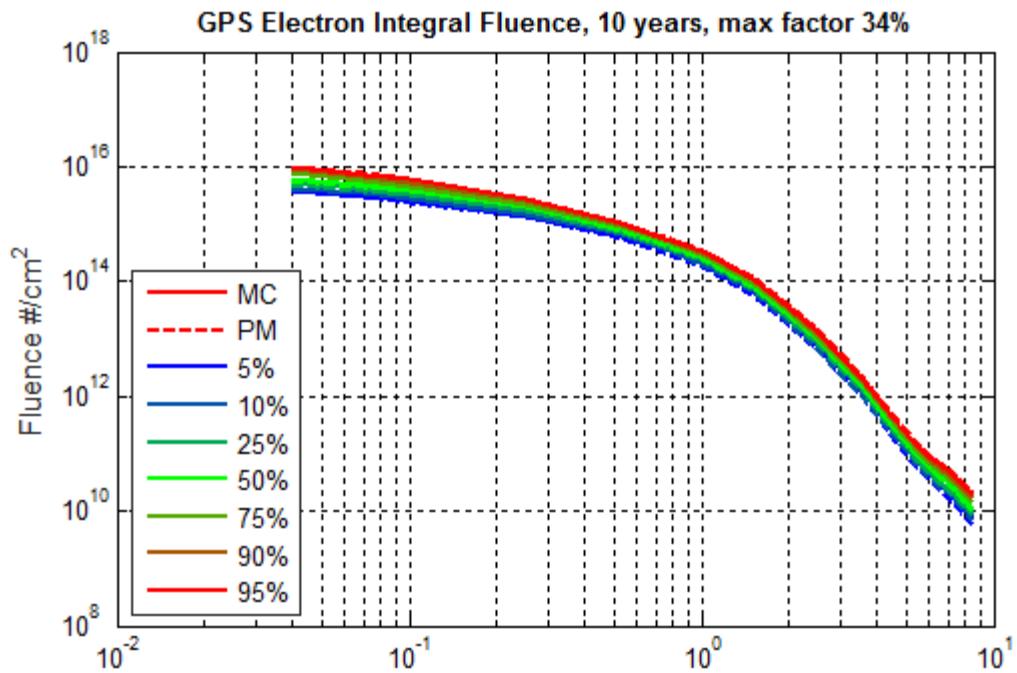
## **AE9/AP9 Release v1.50.001 Monte Carlo Stability Testing**

*[This is an update to parts of an AE9/AP9 project document entitled "Summary of AP9 V1.20 Monte Carlo issue and its fix in AP9 V1.30".]*

In order to verify that the Monte Carlo runs are stable and converge to the same means as the perturbed mean runs, we perform 10-year fluence simulations for several orbits: geostationary (GEO), global positioning (GPS), highly elliptical (HEO), geostationary transfer (GTO), and 800 km sun synchronous (SSO). In each case we compute several confidence levels of the 10-year fluence and compare these confidence levels between Monte Carlo (MC) and perturbed mean (MC) runs. This test ensures that the Monte Carlo runs do not exhibit the instability present in the v1.20 release.

The figure below compares the MC and PM integral electron fluences for a 10-year GPS simulation in AE9 V1.50. The colors are different confidence levels, while the solid and dashed lines indicate the different run types (MC or PM). The top panel shows the fluence spectrum, and the bottom panel shows the ratio of the MC fluence to the PM fluence at each confidence level. In this example, some of the low confidence levels (blue) show the MC higher than the PM by about 30% at high energy. Conversely, the high confidence levels (red) show the MC lower than the PM by about 10%.

Over the range of common orbits evaluated, the V1.50 MC and PM fluences never differ by more than ~40% at any percentile, and usually differ by no more than 10-15%. These are deemed acceptable disagreements given that long timescales in the radiation belts can lead to transient enhancements that may not average out even over 10 years, and the MC runs are intended to reflect that.



## **AE9/AP9 GUI Validation Testing**

The Graphical User Interface (GUI) application, included as part of the AE9/AP9 C++ software, was tested to ensure the user selections and specifications as chosen in the interface were properly reflected in the model runs performed, and that the plotted results displayed the requested parameter values. There were mostly cosmetic changes to the GUI application for the v1.50.001 release; other changes only affected the startup state of interface items.

Validation testing for AE9/AP9 GUI application followed the "Ae9Ap9 v1.35.001 GUI Test Plan"; see Appendix B. This test plan includes a list of the GUI features and behavior for possible selections of Satellite ephemerides, model selections, and plotting behavior. Additionally, three use cases are supplied with specified input parameters, expected outcomes (including expected error messages), and validation procedures for testing the plotting feature.

Initial testing of the GUI included confirming the behavior of the fields given potential selections. Selection and input fields were tested. It was confirmed that the behavior follows the description in the GUI Test Plan.

### *Use Case 1*

Use Case 1 tests the "Mean Elements" ephemeris selection and AE9/AP9 "Perturbed Mean" omnidirectional flux calculation selections for electrons and protons. Output files are in "Year DDD Gmtsec" format and values are tab-delimited. The GUI generated input and output files were inspected to confirm that they produced the files in the specified format. The number of files generated was consistent with expectations from the Test Plan. A plot was generated with the GUI from the 50% Confidence Level flux (Figure 4). It was confirmed that the numbers populating the plot were consistent with the values in the AE9/AP9 output files.

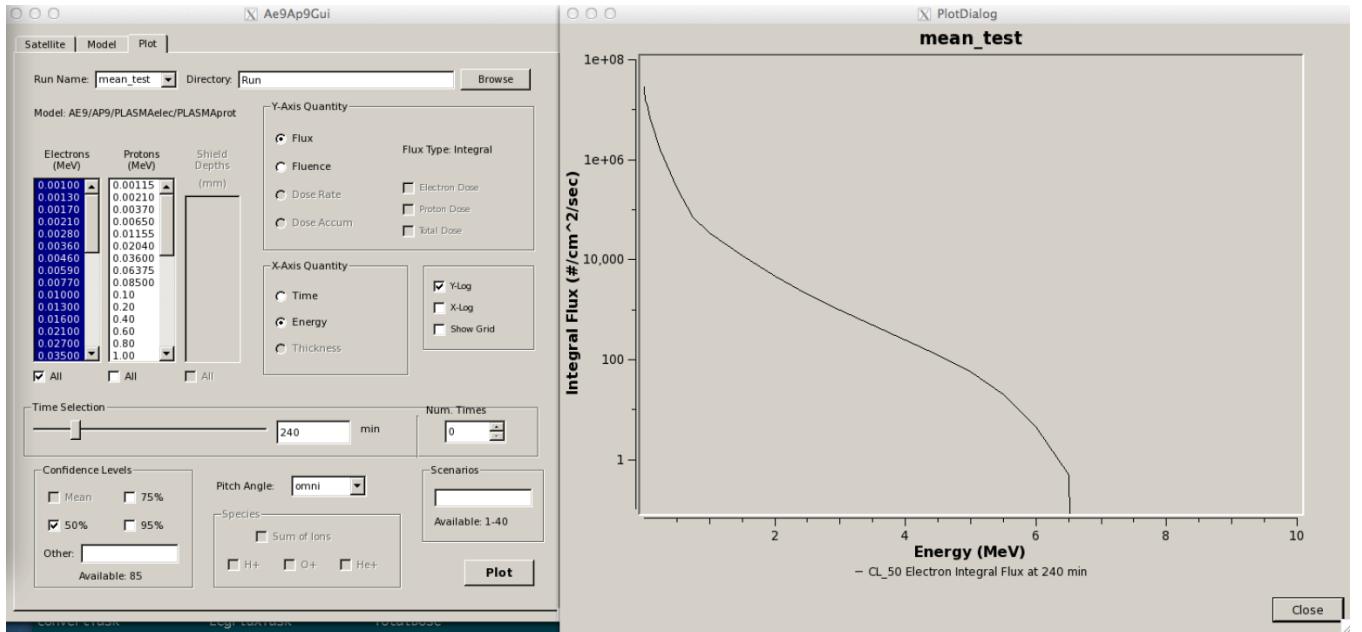


Figure 4: Use Case 1 Plot of Electron Flux from *mean\_test*

Below, we include the header information and the measured flux for the electron data plotted in Figure 4. The SPME model is used to compute the low energy flux. The AE9 model is used to compute the higher energy flux.

Header information and corresponding line (with 240 minutes) from SPME output file, *mean\_test.PLASMAelec.output\_pert\_flux\_conf\_level\_50.txt*:

```
# Modified Ae9Ap9 Model output file: Run/mean_test.PLASMAelec.output_pert_flux_conf_level_50.txt
# incorporating integral data from file: Run/mean_test.AE9.output_pert_flux_<xxx>.txt
# Ae9Ap9 Software Version: 1.35.001
#
# Model type:           SPME
# Particle species:    e-
# Flux type:            Integral
# Flux direction:       Omnidirectional
# Energy levels (MeV): 0.001 0.0013 0.0017 0.0021 0.0028 0.0036 0.0046 0.0059 0.0077 0.01
0.013 0.016 0.021 0.027 0.035
...
2016   349      14400.00      -22.026387      130.988743      5795.79351      2.83212114e+07
2.64255925e+07 2.45498971e+07 2.38376385e+07 2.29432368e+07 2.22284971e+07 2.15859860e+07
2.09230340e+07 2.01240392e+07 1.91941680e+07 1.80257143e+07 1.69421080e+07 1.55191716e+07
1.44378872e+07 1.36399138e+07
```

Header information and corresponding line (with 240 minutes) from AE9 output file, *mean\_test.AE9.output\_pert\_flux\_conf\_level\_50.txt*:

```
# Ae9Ap9 Model output file: Run/mean_test.AE9.output_pert_flux_conf_level_50.txt
# Ae9Ap9 Software Version: 1.35.001
#
# Model type:           AE9
# Particle species:    e-
# Flux type:            Integral
# Flux direction:       Omnidirectional
# Energy levels (MeV): 0.04 0.07 0.1 0.25 0.5 0.75 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7
```

8.5 10

...

```
2016    349      14400.00      -22.026387     130.988743      5795.79351     1.33230562e+07
8.69559291e+06 6.00801380e+06 1.60818812e+06 2.71568518e+05 7.19343784e+04 3.33784916e+04
1.20292724e+04 4.65601002e+03 2.05830227e+03 9.88584412e+02 4.96150333e+02 2.50958100e+02
1.26371549e+02 5.64828176e+01 1.98873670e+01 4.45699452e+00 4.89093075e-01 0.00000000e+00
0.00000000e+00 0.00000000e+00
```

## Use Case 2

Use Case 2 tests "Two Line Element File" ephemeris generation. The selection of an improper file is tested to ensure that error messages are correctly generated. Namely, the Kepler orbit propagator requires an input file with a *single* TLE entry.

An example of the first few lines of the input file, *vapA\_tle.dat*:

```
1 38752U      13275.82096920 .00000027 00000-0 10000-3 0 1773
2 38752  9.9601 95.1283 6818074   0.6473 359.9402 2.67319620 10665
1 38752U      13277.31710353 .00000013 00000-0 10000-3 0 1788
2 38752  9.9555 94.4396 6818035   1.9798 359.7327 2.67319200 10704
1 38752U      13279.93534230 -.00000005 00000-0 10000-3 0 1799
2 38752  9.9606 93.2571 6817829   4.2941 359.3727 2.67318223 10770
...
```

There are 546 total lines in this input file (273 TLE entries).

When this file is specified, the error is shown in Figure 5. The error is corrected by using an input file with the correct number of input elements.

The alternate input file, *cnofs\_tle.dat*, consists of just two lines (one TLE entry):

```
1 32765U 08017A 11150.09749074 +.00010799 +00000-0 +47888-3 0 0797
2 32765 013.0015 105.8044 0295409 031.4522 330.3172 14.8643027916917
```

The AE9/AP9 Monte Carlo mode is tested along with Shield Depth calculations. An error message was raised on attempting to run dose calculations without omnidirectional flux values selected. Figure 6 shows the selected settings that result in the error. Figure 7 shows the error message. After correcting the expected error, by checking "Calculate Omnidirectional Flux" in Advanced Settings, the GUI ran the calculations. An expected informational message indicating that the 99% Confidence Level is outside the limits pops up, shown in Figure 8, but still allows the Shield Dose calculations.

Input files and output files were inspected. The correct number of files was generated. A plot of shield depth at a selected time was generated, shown in Figure 9. The output files were inspected and found to match the values in the plots. Below Figure 9 we include a table of the values plotted as well as the corresponding entries in the AE9 and AP9 output files.

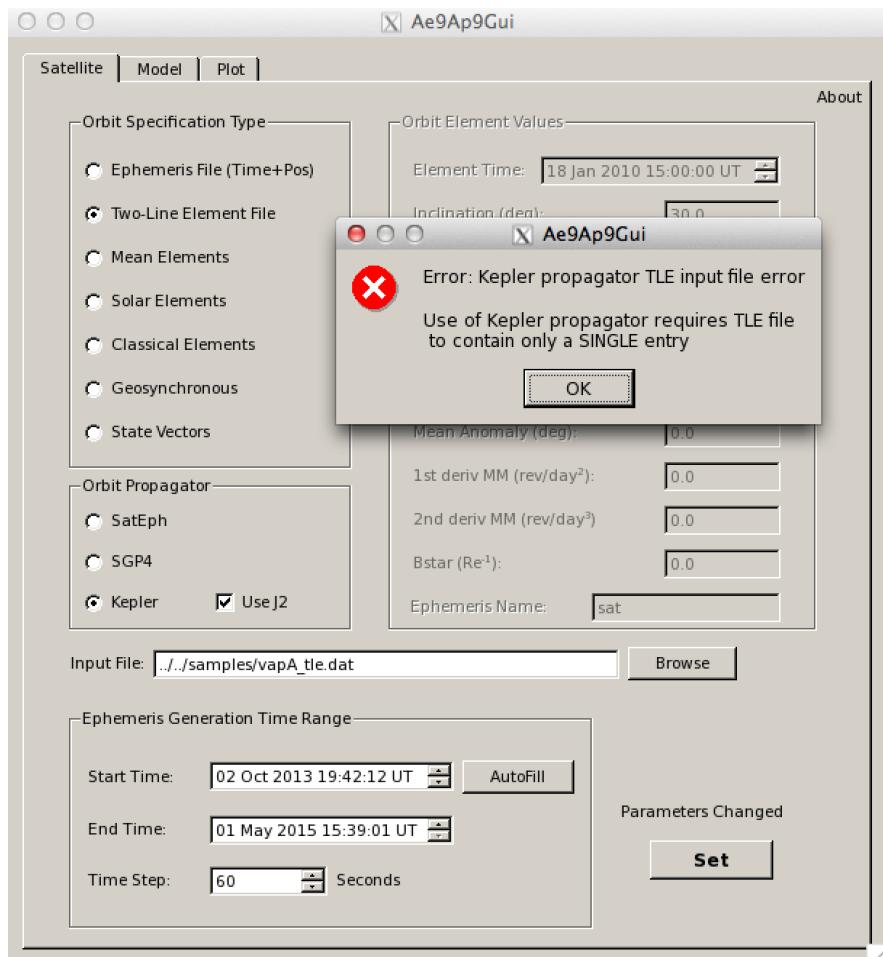


Figure 5: Use Case 2 Error Message for TLE Input File

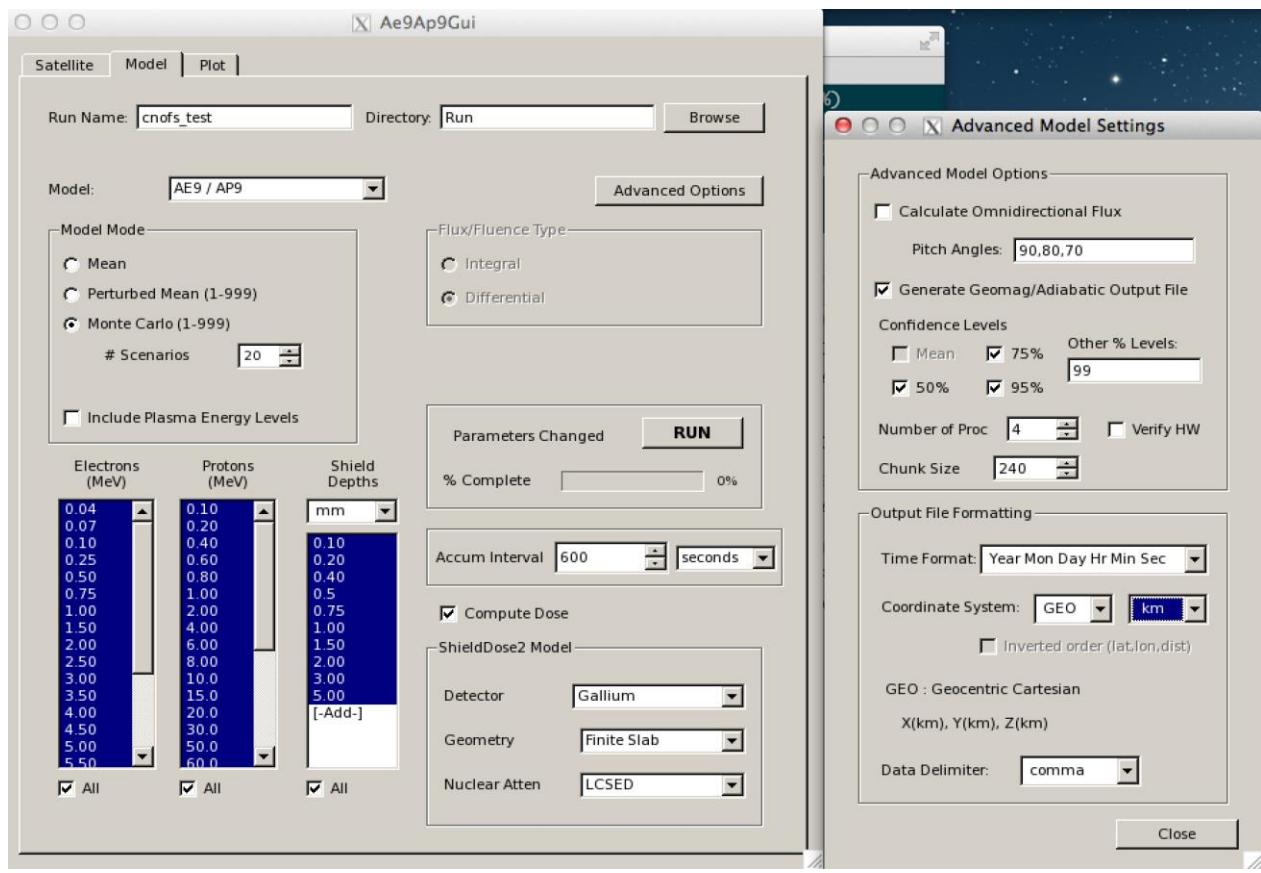


Figure 6: Use Case 2 Shield Dose Rate Settings that led to the Error Message shown in Figure 7. Omnidirectional flux must be calculated in order to determine shield dose rates.

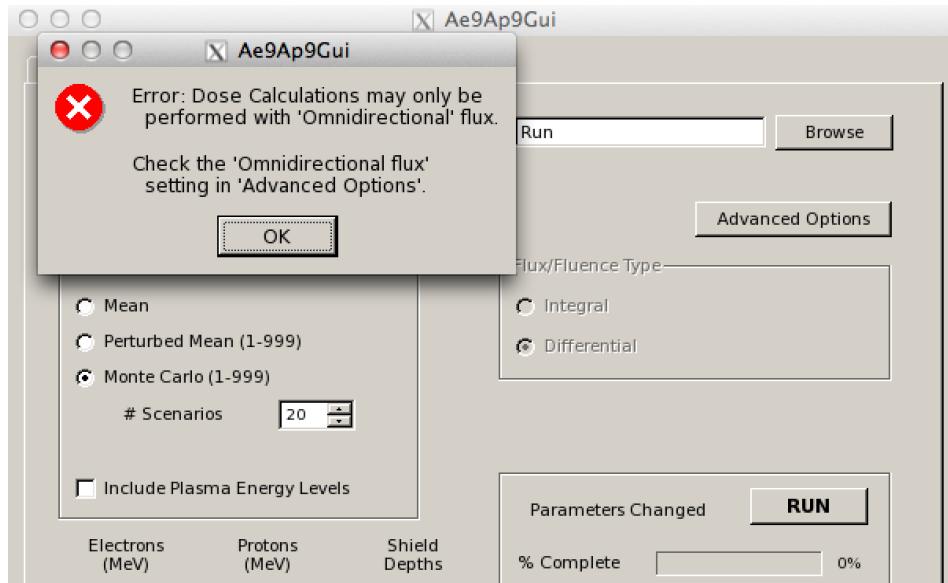


Figure 7: Use Case 2 Error Message from Attempting to Calculate Shield Dose Rate without Calculating Omnidirectional Flux

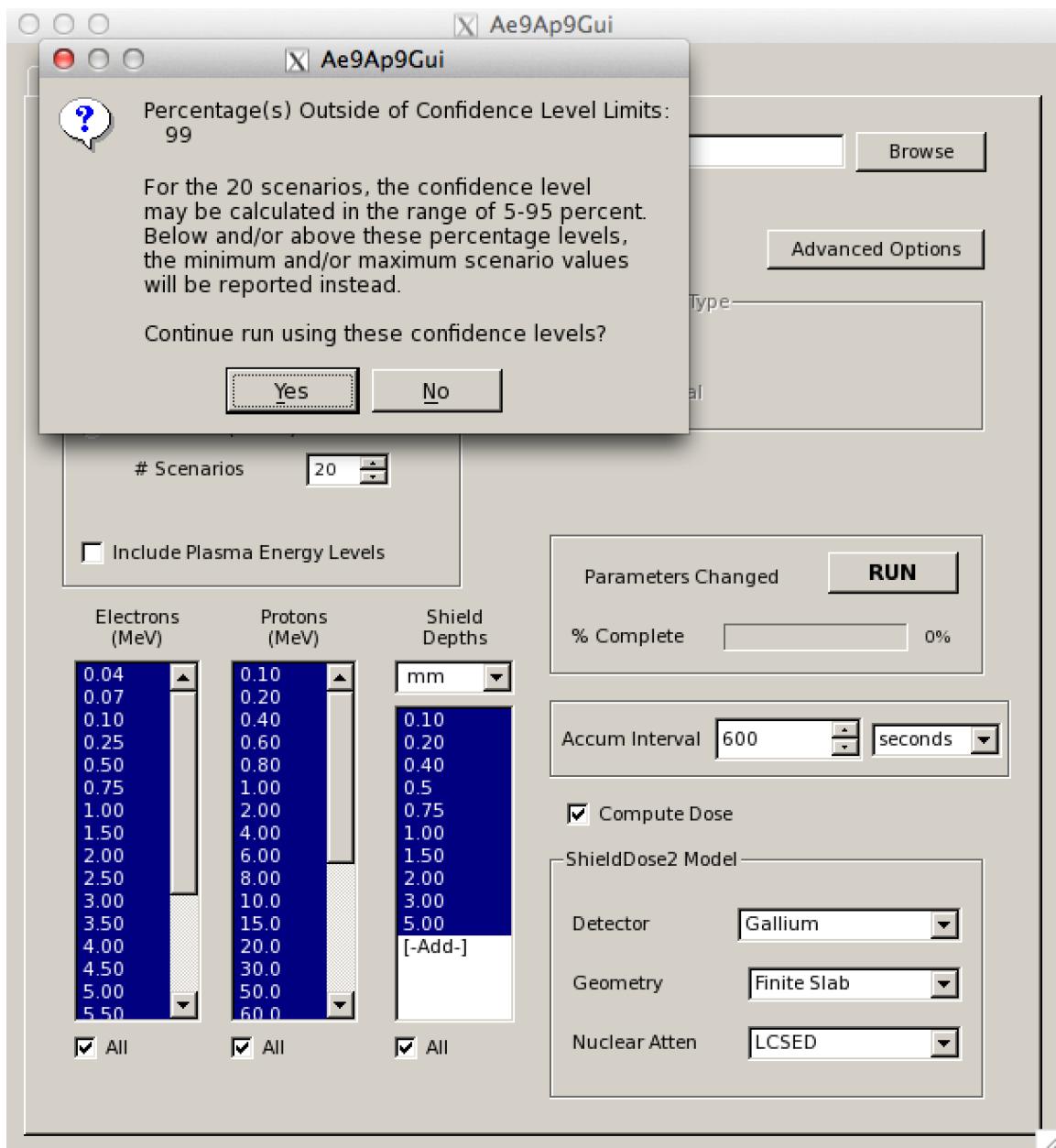


Figure 8: Use Case 2 Expected Informational Message about a Selected Confidence Level being Outside the Limits of the Model

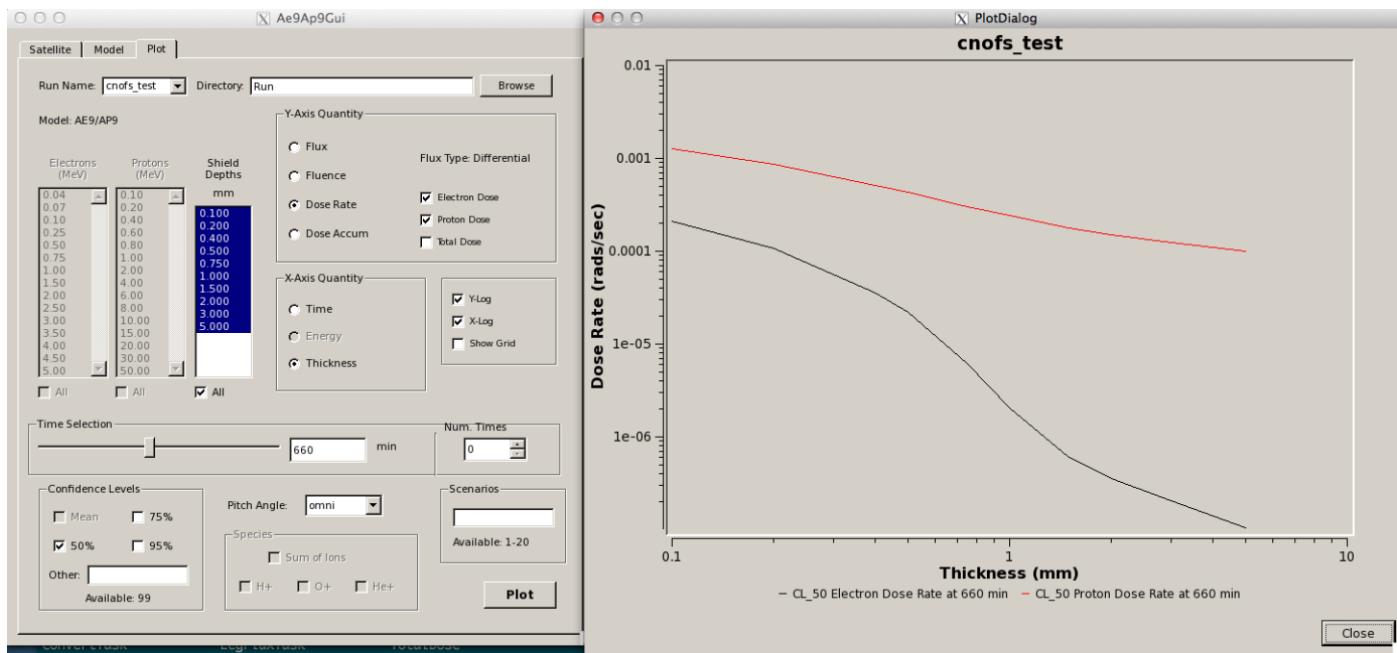


Figure 9: Use Case 2 Plot of Dose Rate as a Function of Shield Thickness

Below, is a Table of the results plotted in Figure 9 from the output file *cnofs\_test\_Plot\_001.txt*. The values are rounded to four significant figures for clarity.

<b>Thickness</b> <b>(mm)</b>	<b>Electron Dose Rate</b> <b>(rads/sec)</b>	<b>Proton Dose Rate</b> <b>(rads/sec)</b>
0.10	2.109E-04	1.274E-03
0.20	1.076E-04	8.624E-04
0.40	3.561E-05	5.096E-04
0.50	2.211E-05	4.294E-04
0.75	6.123E-06	3.033E-04
1.00	2.071E-06	2.424E-04
1.50	6.100E-07	1.765E-04
2.00	3.524E-07	1.502E-04
3.00	2.060E-07	1.250E-04
5.00	1.055E-07	1.005E-04

```
$ grep 5,30,13,20,24 cnofs_test.AE9.output_mc_doserateIntvAvg_conf_level_50.txt
```

```
2011,5,30,13,20,24.02,0.000000,0.000000,0.000000,2.10881415e-04,1.07566608e-04,3.56101900e-05,2.21117834e-05,6.12345752e-06,2.07083775e-06,6.09988518e-07,3.52364097e-07,2.06023913e-07,1.05471017e-07
```

```
$ grep 5,30,13,20,24 cnofs_test.AP9.output_mc_doserateIntvAvg_conf_level_50.txt
```

```
2011,5,30,13,20,24.02,0.000000,0.000000,0.000000,1.27423002e-03,8.62403627e-04,5.09554986e-04,4.29426349e-04,3.03299035e-04,2.42355360e-04,1.76459609e-04,1.50152817e-04,1.25043254e-04,1.00477118e-04
```

### Use Case 3

Use Case 3 tests "Ephemeris File" input and mean differential flux computations given input pitch angles. Output was given in a different coordinate system in each of the test cases. The test ephemeris file and inputs ran without errors. The expected number of output files was generated and both input and output files inspected. A plot was made of the proton and electron flux for a selected pitch angle of 80 degrees, shown in Figure 10. The flux in the output files matched the flux plotted in the GUI.

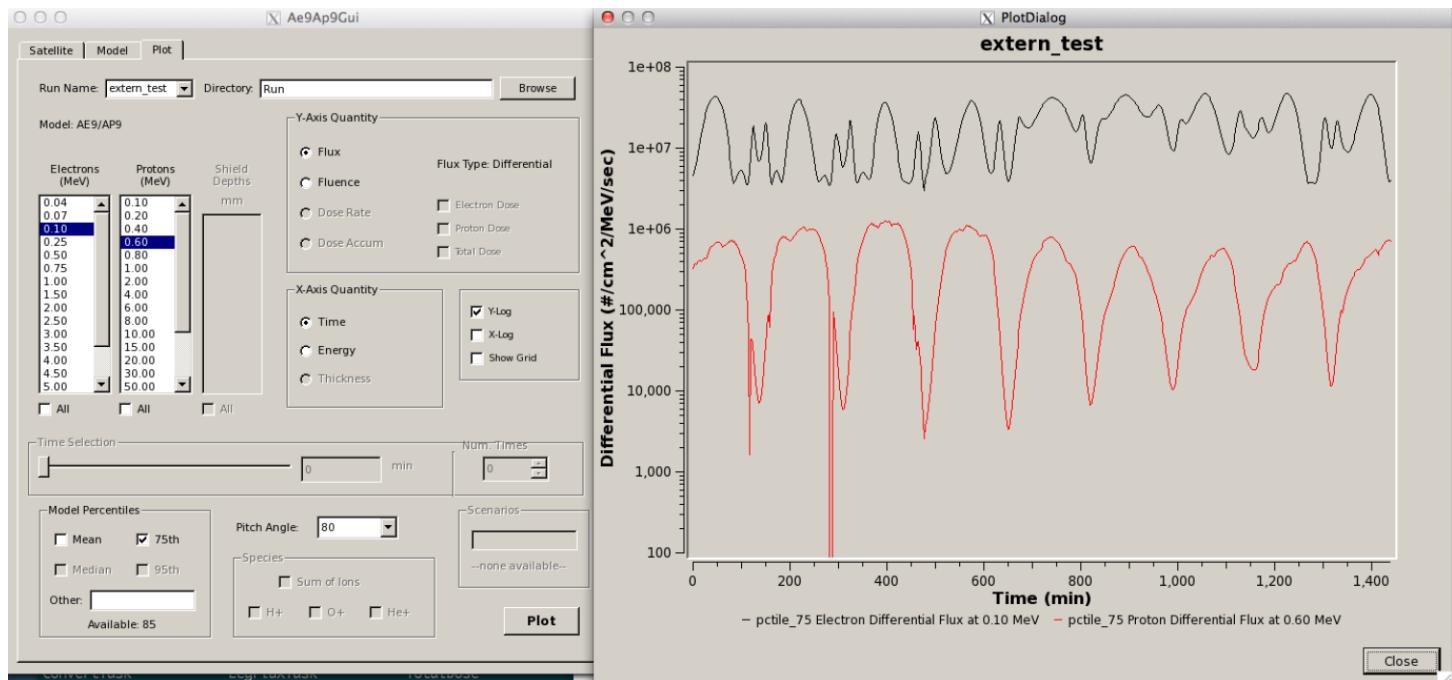


Figure 10: Use Case 3 Plot of Differential Flux vs Time

As an example, we include the first 15 minutes of data from the plot file, *extern\_test\_Plot\_001.txt*. The file includes the electron differential flux at 0.1 MeV (second column) and the proton differential flux at 0.6 MeV (third column) for the 75th percentile. The units of Differential Flux are (#/cm<sup>2</sup>/MeV/sec). The first column is time in minutes.

Data values for the plot in Figure 10:

Time	Electron Flux	Proton Flux
0	4.58956005e+06	3.24163435e+05
2.0000016	4.97074233e+06	3.50024696e+05
4.0000032	5.55868416e+06	3.70899271e+05
6.0000048	6.30044681e+06	3.70130251e+05
8.0000064	7.33425829e+06	3.74529904e+05
9.9999936	8.78713475e+06	3.99996518e+05
11.999995	1.03659086e+07	4.05758573e+05
13.999997	1.22749466e+07	4.07965743e+05
15.999998	1.43402813e+07	3.98406015e+05

Sample lines from the AE9 output file, *extern\_test.AE9.output.pctile\_flux\_75.txt*, with the selected pitch angle of 80 degrees are shown below. The header column describing the format is also included. The flux columns correspond to energies of: Energy levels (MeV): 0.04, 0.07, 0.1, 0.25, 0.5, 0.75, 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 5, 5.5, 6. The electron flux at 0.1 MeV is shown in bold for comparison with the data in the above Table.

```

# datetime(mjd), lat(deg) lon(deg), radius(km), pitchAngle(deg), flux, flux, flux, flux,
flux,flux,flux,flux,flux,flux,flux,flux,flux,flux,flux,flux,flux,flux,flux,flux,flux(#/cm^2/sr/s/MeV)
...
55215.00000000 29.869440      325.306217     9756.936107    80.000  2.08930259e+07 1.36284941e+07
4.58956005e+06 7.69977239e+05 1.05277470e+05 1.48096988e+04 3.04914576e+03 6.34615264e+02
1.75862048e+02 5.86998834e+01 2.67080905e+01 1.21992317e+01 5.64380634e+00 2.78928104e+00
1.31909675e+00 0.00000000e+00 0.00000000e+00

...
55215.00138889 29.998162      329.981690     9870.731249    80.000  2.30567688e+07 1.48148087e+07
4.97074233e+06 8.51027018e+05 1.20233852e+05 1.71252418e+04 3.47948173e+03 7.13547519e+02
1.96258969e+02 6.51552180e+01 2.95043897e+01 1.33237006e+01 6.05786811e+00 2.94771804e+00
1.61265729e+00 0.00000000e+00 0.00000000e+00

```

Since the number of data points to compare is large, a Python script was written and run to compare the flux in the plot file with the AE9 and AP9 output files. The code follows:

The results from running this code showed no difference between any of the values in the plot data file and the AE9/AP9 output files.

### *Summary of GUI Testing*

The validation testing described in this report tested GUI behavior, Input Error-Checking, Input File Generation, Application and Utility Execution, and Plot Generation. Through the three use cases, the GUI performed as expected. Verification of the model calculations was described in previous portions of this document.

## Appendix A: Summary of Ae9Ap9 Model Feature Tests

The table below maps each command line feature or utility to the test that exercises it in the Matlab vs C++ testing

Feature	Note	Test Name																	
		DOSE WATER NOJ2	GEO 10 DAY AE9	GEO 1DAY SPM	GPS 1DAY AE9	GPS 1DAY SPMHE	GPS 1DAY SPMH	GPS 1DAY SPMO	GTO 1DAY AP9	INTPLASMA BOTH	INTPLASMA ELEC	KEPLER GEO CA	KEPLER RV LI	KEPLER SOLAR TISSUE	KEPLER USEJ2 GA	RLL GRAPHITE	SM AL	TLE AIR	GTO 1DAY TOTALDOSE
<b>Command Line Options</b>																			
Model-AE9	Run latest AE9 model		x		x				x	x	x	x	x		x	x	x	x	x
Model-AP9	Run latest AP9 model	x							x	x				x					x
Model-SPME	Run latest SPME model			x						x	x								
Model-SPMH	Run latest SPMH model						x			x									
Model-SPMO	Run latest SPMO model							x											
Model-SPMHE	Run latest SPMHE model					x													
OrbitFile	Specify orbit file name		x	x	x	x	x	x	x						x	x	x		
variable time step - file	Ephem file has variable time step							x	x										x
FluxType-1Pt	1-point differential flux	x	x		x	x		x	x				x	x	x	x	x	x	x
FluxType-2Pt	2-point differential flux			x							SPME, SPMH	SPME							
FluxType-Int	integral flux						x				AE9,AP9	AE9							
FluxOut-mean	output mean flux	x		x	x	x	x	x		x	x	x	x	x	x	x	x	x	x
FluxOut-percentile	output percentile flux (multiple percentiles)				x					x	x								x
FluxOut-perturbed	output perturbed mean flux (multiple scenarios)				x					x	x								x
FluxOut-montecarlo	output monte carlo flux (multiple scenarios)		x		x				x										x
FluenceOut	enable fluence output on mean				x					x	x								x

Feature	Note	Test Name																
		DOSE WATER NOJ2	GEO 10 DAY AE9	GEO 1DAY SPMЕ	GPS 1DAY AE9	GPS 1DAY SPMHE	GPS 1DAY SPMH	GPS 1DAY SPMO	GTO 1DAY AP9	INTPLASMA BOTH	INTPLASMA ELEC	KEPLER GEO CA	KEPLER RV LI	KEPLER SOLAR TISSUE	KEPLER USEJ2 GA	RLL GRAPHITE	SM AL	TLE AIR
	runs																	
DoseRateOut	enable dose rate output on mean runs				x													x
DoseAccumOut	enable cum. dose output on mean runs	x	x	x								x	x	x	x	x	x	x
TimeSpec-MJD	Demo all time specs in and out		x		x	x									x	x		
TimeSpec-YrDDDFrac									x									x
TimeSpec-YrDDDGmt				x														
TimeSpec-YrMoDaGmt							x											
TimeSpec-YrMoDaHrMnSc								x										
InTimeSpec-MJD			x		x	x									x	x		
InTimeSpec-YrDDDFrac									x									x
InTimeSpec-YrDDDGmt				x														
InTimeSpec-YrMoDaGmt							x											
InTimeSpec-YrMoDaHrMnSc								x										
CoordSys-GEI	Demo all coordinate systems in and out				x													
CoordSys-GEO				x														
CoordSys-GDZ						x		x									x	
CoordSys-GSM																	x	
CoordSys-GSE							x											
CoordSys-SM																x		
CoordSys-MAG						x												
CoordSys-SPH			x													x		
CoordSys-RLL																		

Feature	Note	Test Name																
		DOSE WATER NOJ2	GEO 10 DAY AE9	GEO 1DAY SPMЕ	GPS 1DAY AE9	GPS 1DAY SPMHE	GPS 1DAY SPMH	GPS 1DAY SPMO	GTO 1DAY AP9	INTPLASMA BOTH	INTPLASMA ELEC	KEPLER GEO CA	KEPLER RV LI	KEPLER SOLAR TISSUE	KEPLER USEJ2 GA	RLL GRAPHITE	SM AL	TLE AIR
InCoordSys-GEI					x													x
InCoordSys-GEO				x														
InCoordSys-GDZ							x											
InCoordSys-GSM									x									
InCoordSys-GSE								x										
InCoordSys-SM																	x	
InCoordSys-MAG					x													
InCoordSys-SPH		x																
InCoordSys-RLL															x			
CoordUnits-Re	Demo km vs Re choice		x	x	x			x									x	
CoordUnits-km							x									x		
InCoordUnits-Re			x	x	x			x									x	
InCoordUnits-km							x									x		
CoordOrder- Standard	explicit coord order								x									x
CoordOrder- Inverted	try inverted coord order (e.g., with GDZ)															x		
InCoordOrder- Standard									x									x
InCoordOrder- Inverted																x		
DataDelim-Comma	Data delimiters, in and out		x		x	x		x								x	x	
DataDelim-Space										x								x
DataDelim-Tab				x														
InDataDelim- Comma			x		x	x		x								x	x	
InDataDelim-Space									x									x
InDataDelim-Tab				x														
DirFile	Specify incident directions via file					x												

Feature	Note	Test Name																	
		DOSE WATER NOJ2	GEO 10 DAY AE9	GEO 1DAY SPMЕ	GPS 1DAY AE9	GPS 1DAY SPMHE	GPS 1DAY SPMH	GPS 1DAY SPMO	GTO 1DAY AP9	INTPLASMA BOTH	INTPLASMA ELEC	KEPLER GEO CA	KEPLER RV LI	KEPLER SOLAR TISSUE	KEPLER USEJ2 GA	RLL GRAPHITE	SM AL	TLE AIR	GTO 1DAY TOTALDOSE
PitchFile	Specify incident dirs via pitch angle file							x											
PitchAngles	Specify incident dirs via pitch angle list			x															
AdiabatOut-True	Enable output of adiabatic invariants			x		x	x	x											
AdiabatOut-False	Disable output of adiabatic invariants								x										x
AdiabatOut-Omitted	Default behavior for output of ad.invs.	x	x		x				x	x	x	x	x	x	x	x	x	x	x
MCEpoch-Omit	omit MC epoch arg on MC run	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
MCEpoch-Set	Set MC epoch on MC run to value not equal to first time step		x						x										x
ChunkSize-Omitted	Use default points per call	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
ChunkSize-100	Use 100 points per call								x										x
Aggregate-mean	Test aggregation mean (vestigial, no meaning)				x				x	x									x
Aggregate-median	Test aggregation median (50 CL)				x				x	x									x
Aggregate-percent	Test aggregation percent CL				x				x	x									x
FluxPert-Omitted	Default behavior for perturbing flux map (MC or PM runs)	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
FluxPert-Enable	Enable perturbing flux map (MC runs, not percentile runs?)								x										x
FluxPert-Disable	Disable perturbing flux map (MC runs, not percentile runs?)		x																
DoseDepths	Demo all dose calculation	x	x		x				x			x	x	x	x	x	x	x	x

Feature	Note	Test Name															
		DOSE WATER NOJ2	GEO 10 DAY AE9	GEO 1DAY SPME	GPS 1DAY AE9	GPS 1DAY SPMHE	GPS 1DAY SPMH	GPS 1DAY SPMO	GTO 1DAY AP9	INTPLASMA BOTH	INTPLASMA ELEC	KEPLER GEO CA	KEPLER RV LI	KEPLER SOLAR TISSUE	KEPLER USEJ2 GA	RLL GRAPHITE	SM AL
	options																
DoseDepths-OutOfOrder	swap order of some depths								x								
DoseDepthUnits-millimeters		x			x							x	x	x	x	x	x
DoseDepthUnits-mm			x														x
DoseDepthUnits-mils								x									
DoseDepthUnits-gcm2															x		
DoseGeometry-spherical		x	x		x						x	x	x	x	x	x	x
DoseGeometry-finiteslab								x									
DoseGeometry-semiinfiniteslab																x	
DoseDetector-aluminum																	x
DoseDetector-graphite															x		
DoseDetector-silicon					x												
DoseDetector-air																	x
DoseDetector-bone			x														
DoseDetector-calcium										x							
DoseDetector-gallium														x			
DoseDetector-lithium											x						
DoseDetector-glass								x									
DoseDetector-tissue												x					x
DoseDetector-water		x															
DoseAttnMode-none								x									
DoseAttnMode-nuclearinteractions		x	x		x						x	x	x	x	x	x	x

Feature	Note	Test Name																	
		DOSE WATER NOJ2	GEO 10 DAY AE9	GEO 1DAY SPME	GPS 1DAY AE9	GPS 1DAY SPMHE	GPS 1DAY SPMH	GPS 1DAY SPMO	GTO 1DAY AP9	INTPLASMA BOTH	INTPLASMA ELEC	KEPLER GEO CA	KEPLER RV LI	KEPLER SOLAR TISSUE	KEPLER USEJ2 GA	RLL GRAPHITE	SIM AL	TLE AIR	GTO 1DAY TOTALDOSE
DoseAttnMode-nuclearandneutrons														x					
AccumMode-cumul	Output all points				x														
AccumMode-full	only do the last point	x							x			x	x	x	x	x	x	x	x
AccumMode-interval	AccumInterval=1 day as realistic user value	x																	
OrbTLE	Try all orbit propagator options																	x	
OrbStart	x								x	x	x	x	x	x			x	x	
OrbEnd	x								x	x	x	x	x	x			x	x	
OrbStep	x								x	x	x	x	x	x			x	x	
OrbPropType-Kepler	x								x	x	x	x	x	x			x	x	
OrbUseJ2-true												x							x
OrbUseJ2-false	x								x	x	x								
OrbUseJ2-omitted		x	x	x	x	x	x	x	x					x	x	x	x	x	
OrbElemTime	x								x	x	x	x	x	x					x
OrbIncl	x											x	x						x
OrbRAAN	x													x					
OrbEcc	x													x					
OrbArgPer	x													x					
OrbMeanAnom	x																		
OrbMeanMot	x																		
OrbAltPer													x						x
OrbAltApog													x						x
OrbSemiMaj														x					
OrbLTApog												x							x

Feature	Note	Test Name																
		DOSE WATER NOJ2	GEO 10 DAY AE9	GEO 1DAY SPMЕ	GPS 1DAY AE9	GPS 1DAY SPMHE	GPS 1DAY SPMH	GPS 1DAY SPMO	GTO 1DAY AP9	INTPLASMA BOTH	INTPLASMA ELEC	KEPLER GEO CA	KEPLER RV LI	KEPLER SOLAR TISSUE	KEPLER USEJ2 GA	RLL GRAPHITE	SM AL	TLE AIR
OrbLTMaxIncl														x				x
OrbTimPer														x				
OrbPosXyz													x					
OrbVelXyz												x						
OrbGeoLon									x	x	x							x
Command Line Utilities																		
IntegralPlasma-Elec	Compute integral electron channels in plasma energy range										x							
IntegralPlasma-Prot	Compute integral proton channels in plasma energy range									x								
IntegralPlasma-Both	Compute integral channels in plasma energy range both species									x								
TotalDose	Compute total dose percentiles from summed prot+elec dose									x								x

## Appendix B: Ae9Ap9 GUI Test Plan

These tests are concerned with transforming the selections and specifications made within the user interface into the appropriate model run input files, the invocation of the processing using the CmdLineAe9Ap9 application and its two support utilities, and the proper access and presentation of the data values from the generated output files. These tests cannot be done automatically due to the required user interaction with the graphical user interface. Due to the extensive number of model and option parameters that are able to be specified through this user interface, not all permutations of the various settings can be tested within a reasonable timescale. The verification of the actual model calculation results is performed elsewhere.

Testing of this Ae9Ap9 GUI application can be grouped into five categories:

- **GUI Behavior** – a selection in one control item changes what other controls are available.
- **Input Error-Checking** – the user-entered values are within their valid ranges, or the combination of parameters is permitted.
- **Input File Generation** – all user selections of model parameters and options are correctly represented in the generated model run input files.
- **Application and Utility Execution** – the required model and utility applications are performed.
- **Plot Generation** – the values displayed in the generated plots are being correctly extracted from the proper model run output files and data fields, according to the user selections.

### GUI Behavior

#### *Satellite Tab*

The ephemeris specification panel offers a large choice of orbit definitions, each of which has a specific set of values and/or input requirements. These input items are toggled in and out of visibility in order to keep an uncluttered interface; when nothing takes its place, those items are grayed out (inactive).

Item Selected	Right Side Items Active	Lower Section Items Active
Ephemeris File	Time Format, Coordinate System, Data Delimiter	Input File
Two-Line Element File	<nothing active>	Input File Start Time, End Time, Time Step, AutoFill
Mean Elements	Element Time, Inclination, RA of Ascend Node, Argument of Perigee, Eccentricity, Mean Motion, Mean Anomaly, 1 <sup>st</sup> Deriv MM*, 2 <sup>nd</sup> Deriv MM*, Bstar*, Ephemeris Name [* inactive w/ Kepler]	SatEph, SGP4, Kepler Start Time, End Time, Time Step
Solar Elements	Element Time, Inclination, LT of Max Inclin, LT of Apogee, Apogee Altitude*, Perigee Altitude*, Mean Anomaly, Ephemeris Name [* checkbox toggles these to Eccentricity and SemiMajor Axis]	SatEph, SGP4, Kepler Start Time, End Time, Time Step
Classical Elements	Element Time, Inclination, RA of Ascend Node, Argument of	SatEph, SGP4, Kepler

	Perigee, Apogee Altitude*, Perigee Altitude*, Mean Anomaly, Ephemeris Name [* checkbox toggles these to Eccentricity and SemiMajor Axis]	Start Time, End Time, Time Step
Geosynchronous	Element Time, Geographic E Longitude, Ephemeris Name	SatEph, SGP4, Kepler Start Time, End Time, Time Step
State Vectors	Element Time, GEI X/Y/Z Positions, GEI X/Y/Z Velocities, Ephemeris Name	SatEph, SGP4, Kepler Start Time, End Time, Time Step
SatEph	<defined by Orbital Specification Type selection>	SatEph, SGP4, Kepler
SGP4	<defined by Orbital Specification Type selection>	SatEph, SGP4, Kepler
Kepler	<defined by Orbital Specification Type selection>	SatEph, SGP4, Kepler, Use J2

### *Model Tab*

The Model specification panel enables the user to specify the parameters relevant to the chosen model type. Input fields are toggled in and out of visibility in order to keep an uncluttered interface, and avoid user confusion. Selections made on this panel also affect options that are available on the 'Advanced Options' dialog panel.

Model selected:

*AE9/AP9*

- Model Mode: Mean, Perturbed Mean, Monte Carlo, Scenarios<sup>7</sup>
- checkbox Include Plasma Energy Levels
- Electrons energy list<sup>8</sup>
- Protons energy list<sup>9</sup>
- Shield Depths<sup>10</sup>, mm|mils|g/cm<sup>2</sup>
- Flux/Fluence Types: Integral, Differential
- Accum Interval, days|seconds
- checkbox Compute Dose
- ShieldDose2 Model<sup>10</sup>: Detector, Geometry, Nuclear Atten
- Advanced Options Dialog
  - checkbox Calculate Omnidirectional Flux, Pitch Angles (when not checked)
  - checkbox Generate Geomag/Adiabatic Output File
  - Model Percentiles<sup>11</sup>: Mean, Median, 75<sup>th</sup>, 95<sup>th</sup>, Other Percentiles
  - Confidence Levels<sup>7</sup>: 50%, 75%, 95%, Other % Levels
  - Number of Proc, checkbox Verify HW
  - Chunk Size
  - Output File Formatting: Time Format, Coordinate System, Data Delimiter

---

<sup>7</sup> Active when Perturbed Mean or Monte Carlo is selected

<sup>8</sup> Includes set of energies less than 0.04 MeV when 'Include Plasma Energy Levels' checkbox is checked

<sup>9</sup> Includes set of energies less than 0.10 MeV when 'Include Plasma Energy Levels' checkbox is checked

<sup>10</sup> Active when 'Compute Dose' checkbox is checked

<sup>11</sup> Active when Mean is selected

### *Plasma (SPM)*

- Model Mode: Mean, Perturbed Mean, Scenarios<sup>12</sup>
- Electrons energy list (keV)
- Ions energy list (keV)
- Available Species: checkboxes Electrons, H+, O+, He+
- Accum Interval, days|seconds
- Advanced Options Dialog
  - checkbox Calculate Omnidirectional Flux, Pitch Angles (when not checked)
  - checkbox Generate Geomag/Adiabatic Output File
  - Model Percentiles<sup>13</sup>: Mean, Median, 75<sup>th</sup>, 95<sup>th</sup>, Other Percentiles
  - Confidence Levels<sup>12</sup>: 50%, 75%, 95%, Other % Levels
  - Number of Proc, checkbox Verify HW
  - Chunk Size
  - Output File Formatting: Time Format, Coordinate System, Data Delimiter

### *AE8/AP8*

- Activity Level: Solar Minimum, Solar Maximum
- Electrons energy list
- Protons energy list
- Shield Depths<sup>14</sup>, mm|mils|g/cm<sup>2</sup>
- Flux/Fluence Types: Integral, Differential
- Accum Interval, days|seconds
- checkbox Compute Dose
- ShieldDose2 Model<sup>14</sup>: Detector, Geometry, Nuclear Atten
- Advanced Options Dialog
  - checkbox Use Native Epoch Magnetic Field
  - checkbox Translate SAA to Ephemeris Epoch
  - Output File Formatting: Time Format, Coordinate System, Data Delimiter

### *CRRES ELE/PRO*

- Activity Levels: Electrons Ap15, Protons
- Electrons energy list
- Protons energy list
- Shield Depths<sup>15</sup>, mm|mils|g/cm<sup>2</sup>
- Flux/Fluence Types: Integral, Differential
- Accum Interval, days|seconds
- checkbox Compute Dose
- ShieldDose2 Model<sup>15</sup>: Detector, Geometry, Nuclear Atten

---

12 Active when Perturbed Mean is selected

13 Active when Mean is selected

14 Active when 'Compute Dose' checkbox is checked

15 Active when 'Compute Dose' checkbox is checked

- Advanced Options Dialog
  - checkbox Use Native Epoch Magnetic Field
  - checkbox Translate SAA to Ephemeris Epoch
  - Output File Formatting: Time Format, Coordinate System, Data Delimiter

#### CAMMICE/MICS

- DST: All Conditions, Quiet Conditions
- Energy Bins list (keV) – 'all' selected, *not changeable*
- Pitch Angle and Species: Pitch Angle Bin, checkboxes Sum of Ions, H+, O+, He+
- Accum Interval, days|seconds
- Advanced Options Dialog
  - Output File Formatting: Time Format, Coordinate System, Data Delimiter

#### Plot Tab

Run Name: collects information from input files associated with selected Run Name, in Run directory.

Model: summary of specific models associated with selected Run Name

Electrons energy list: list of selected energies from model run

Protons/Ions energy list: list of selected energies from model run

Shield Depths list<sup>16</sup>: list of depths from model run

Y-Axis Quantity: Flux, Fluence, Dose Rate<sup>16</sup>, Dose Accum<sup>16</sup>

X-Axis Quantity: Time, Energy, Thickness<sup>16</sup>

Flux Type: type from model run

checkboxes Electron, Proton and Total Dose<sup>16</sup>

Time Selection: active only when X-Axis Quantity selection is Energy or Thickness, and Num Times is set to '0'.

Model Percentiles/Confidence Levels and Pitch Angle: availability mirrors selections made in Model tab 'Advanced Options' for AE9/AP9 and PLASMA models

Species: availability mirrors selections made in Model tab species selections for PLASMA and CAMMICE/MICS models

Scenarios: active only for AE9/AP9 and PLASMA models with either Perturbed Mean or Monte Carlo mode.

---

16 if model run included shield dose calculations, and Dose Rate or Dose Accum selected

## **Input File Generation, Input Error-Checking, Application and Utility Execution and Plot Generation**

The primary function of the Ae9Ap9 GUI application is to generate model run input files whose contents reflect the user selections made. Three use cases are used to demonstrate the process for these categories. Only a small subset of the possible combinations of parameter specifications will be tested here, but these cases attempt to cover many different types of features.

### Use case 1:

Sat Tab:

Orbit Specification Type: select Mean Elements  
Orbit Propagator: SatEph  
Element time: 14 Dec 2016 15:00:00 UT  
Inclination: 22.0  
RA of Ascend Node: 0.0  
Argument of Perigee: 45.0  
Eccentricity: 0.2  
Mean Motion: 7.5  
Mean Anomaly: 46.0  
1<sup>st</sup> Deriv MM: 0.0  
2<sup>nd</sup> Deriv MM: 0.0  
Bstar: 0.0  
Ephemeris Name: 'mean\_test'  
Start Time: 14 Dec 2016 00:00:00 UT  
End Time: 15 Dec 2016 00:00:00 UT  
Time Step: 60  
Press 'Set'

Model Tab:

Run Name: 'mean\_test'  
Model: AE9/AP9  
Model Mode: Perturbed Mean  
# Scenarios: 40  
select 'Integral' flux type  
set 'Accum Interval' to 0 seconds  
Press 'Advanced Options':  
check 'Generate Geomag/Adiabatic Output File'  
Add '85' in 'Other % Levels'  
set Number of Proc to 4, uncheck 'Verify HW'  
set Time Format to 'Year DDD Gmtsec'  
set Coordinate System to 'GDZ'  
check 'inverted order'  
set Data Delimiter to 'Tab'  
(press Close)

press 'Run'

(GUI controls will become 'grayed-out', and the progress bar will show the current status.  
*<(this run may take several minutes)>*

Watch the progress bar – when it reaches 100%, a small dialog window will appear, with its own progress bar with 'Plasma Integral Flux calculations' in its title; it will disappear when it reaches 100%.

At the conclusion of the calculations, the GUI controls will return to normal. Leave the GUI window open, as the current settings will be referenced in when reviewing the generated files.

In a separate terminal window, navigate to the 'Run' directory, and enter the command

`ls mean_test*input.txt`

Five files should be listed, representing the inputs for five separate model runs performed by the GUI application. The 'ephem' run is done first, as its resulting ephemeris file is used by the other four.

`mean_test.AE9.input.txt`  
`mean_test.AP9.input.txt`  
`mean_test.Ephem.input.txt`  
`mean_test.PLASMAelec.input.txt`  
`mean_test.PLASMAprot.input.txt`

View the contents of these files, and compare their parameters to the selections on the GUI panels, and referencing the User's Guide keyword/value parameter charts:

*mean\_test.Ephem.input.txt*

shows the specified element time, element values, propagator, the start/stop time, time step from the satellite tab; the time, coordinate and delimiter specifications from the Advanced Options dialog are also seen in the input file, as is the Number of processors (the negative number indicates to *not* 'verify HW'). The name of the generated ephemeris file, based upon the 'Ephemeris Name', is also shown.

*mean\_test.PLASMAprot.input.txt*

shows the model name 'PLASMA', the proton species via the ModelDB specification, *2pt-differential* flux, the list of proton energies (at the 'Plasma' level). Because the Plasma model cannot directly calculate 'integral' fluxes, it uses the 2pt-differential flux mode, with a second set of energies (all at 0.1); the post-processing uses these results. The input file also the 'perturbed' flux option, for 40 scenarios, and standard aggregation confidence levels of 50, 75 and 95; the additional 85 is specified on a separate line. The output file prefix is constructed from the specified 'Run Name' and particle species. The OrbitFile parameter specifies the ephemeris file that was generated by the 'Ephem' model run. The file also shows the time, coordinate and delimiter specifications, and number of processors, from the Advance Options dialog. Because the 'Generate Geomag/Adiabatic' checkbox was checked, the 'AdiabatOut: True' parameter is present, but only in this model run input file – these results are model independent, and therefore only need to be calculated once.

*mean\_test.PLASMAelec.input.txt* is much like its proton counterpart, except for specifying the

Plasma electron ModelDB, the list of electron energies (at the Plasma level, and the second set, all at 0.04 MeV), and the appropriate output file prefix.

*mean\_test.AP9.input.txt* shows the model name 'AP9', the proton species via the ModelDB specification, Integral flux, the list of proton energies; the 'perturbed' flux option, for 40 scenarios, and standard aggregation confidence levels of 50, 75 and 95; the additional 85 is specified on a separate line. The output file prefix is constructed from the specified 'Run Name' and model name. The accumulation interval is shown as 600 seconds. The OrbitFile parameter specifies the ephemeris file that was generated by the 'Ephem' model run. The input file also shows the time, coordinate and delimiter specifications, and number of processors, from the Advance Options dialog.

*mean\_test.AE9.input.txt* is nearly identical to its proton counterpart, save the model name, ModelDB specification, energy list, and output file prefix.

#### *Application and Utility Execution*

For this case, pushing the 'run' button in the GUI invokes the execution of the 'CmdLineAe9Ap9' application five times, and a subsequent execution of the IntegralPlasma post-processing utility application. This series of executions generates one ephemeris file, and a total of 353 model results files (`ls mean_test*output*.txt | wc -l`). The presence of these files indicates the proper execution of these applications. Notable files included in this collection include:

`ephem_mean_test.dat` – the generated ephemeris file  
`mean_test.*.output_pert_flux_???.txt` – 160 files, 4 sets (Plasma electron & proton, AE9, AP9) of 40 scenario files each  
`mean_test.*.output_pert_flux_conf_level_???.txt` – 16 files, 4 sets of 4 confidence levels (50, 75, 95 and the additional 85)  
`mean_test.PLASMAprot.output_adiabat.txt` – the generated adiabatic invariant coordinates  
`mean_test.PLASMA*.output_pert*.txt` – 176 files of 'plasma' integral results that have been modified to incorporate AE9 and AP9 results; examine the headers of these files – the first line should state the file has been modified, and the 'flux type' is now showing 'Integral'. The presence of these lines indicate the proper execution of the 'IntegralPlasma' utility application by the GUI.

#### *Plot Generation*

In the GUI, switch to the Plot tab

When 'Run Name' shows 'mean\_test', the model list should show both Plasma models and AE9/AP9. The electron and proton energy lists should show those picked on the Model tab; the shield depth list should be blank. Under the 'other' box for the Confidence Levels, it should report '85' as being available, and the 'Scenarios' box show 1-40 as being available.

Select 'Flux', then check the 'All' checkbox under the Electrons list; select 'Energy' under X-Axis quantity. Check the '50%' under Confidence Levels. Enter '240' in the Time Selection box, press 'Plot'. In a terminal window, look for the most recent file named in the form

'Run/mean\_test\_Plot\_???.txt', and view the file, comparing the numeric values to the plot – please note that this single line plot comes from two files, the Plasma for the energies lower than 0.04 MeV, AE9 for the remainder.

Also view the files 'mean\_test.PLASMAelec.output\_pert\_flux\_conf\_level\_50.txt' and

'mean\_test.AE9.output\_pert\_flux\_conf\_level\_50.txt' – this will be the electron output files from which these values are extracted for plotting. The time value of '240 minutes' is in reference to the start time of the ephemeris (the input file 'cnofs\_test.Ephem.input.txt' shows the start time as 2016 349 0); adding 240 minutes to the GMTsec value gives 14460. Using this time as a reference in the two files, the flux values on the lines should match those shown (referencing their energy levels) in the generated file associated with the plot.

### Use case 2:

Sat Tab:

Orbit Specification Type: select Two-Line Element File

Orbit Propagator: Kepler, use J2

Input File: ../../samples/vapA\_tle.dat

Press 'AutoFill'

– observe start time set to 02 Oct 2013 19:42:12 UT, end time set to 01 May 2015 15:39:01 UT

Press 'Set'

==> expected error: Kepler limited to TLE file with single elements

revise Input File: ../../unitTests/cnofs\_tle.dat

Press 'AutoFill'

– observe start time set to 30 May 2011 02:20:24 UT, end time set to 31 May 2011 02:20:24

UT

Time Step: 60

Press 'Set'

Model Tab:

Run Name: 'cnofs\_test'

Model: AE9/AP9

Model Mode: Monte Carlo

# Scenarios: 20

unchecked 'include Plasma Energy Levels'

check 'Compute Dose'

(this automatically selects 'all' proton and electron energies, activates the Shield Depths list)

use '-Add-' line in Shield Depths list to add values 0.50, 0.75, 1.00, 1.50, 2.00, 3.00, 5.00

check 'All' under Shield Depths list

set 'Accum Interval' to 600 seconds

set Detector to 'Gallium'

set Geometry to 'Finite Slab'

set Nuclear Atten to 'LCSED'

Press 'Advanced Options':

Uncheck 'Calculate Omnidirectional Flux'

Enter '90,80,70' in Pitch Angles

check 'Generate Geomag/Adiabatic Output File'

Add '99' in 'Other % Levels'

set Number of Proc to 4, uncheck 'Verify HW'

set Time Format to 'Year Mon Day Hr Min Sec'

set Coordinate System to 'GEO', 'km'

```
set Data Delimiter to 'Comma'
(press Close)
press 'Run'
==> expected error: Dose calculations not allowed with unidirectional flux
Press 'Advanced Options':
  check 'Calculate Omnidirectional Flux' (this deactivates the Pitch Angle list)
  (press Close)
Press 'Run'
==> expected informational message: '99' is outside of Confidence Level limits (press 'Yes')
(GUI controls will become 'grayed-out', and the progress bar will show the current status.
<this run may take several minutes>
Watch the progress bar – when it reaches 100%, you may see a small dialog window briefly appear, with its own progress bar with 'Total Dose' in its title (on sufficiently fast machines, it may not appear at all).
At the conclusion of the run, the GUI controls will return to normal. Leave it running, as the current settings will be referenced in when reviewing the generated files.
```

In a separate terminal window, navigate to the 'Run' directory, and enter the command

```
ls cnofs_test*input.txt
```

Three files should be listed, representing the inputs for three separate model runs performed by the GUI application. The 'ephem' run is done first, as its resulting ephemeris file is used by the other two.

```
cnofs_test.AE9.input.txt
```

```
cnofs_test.AP9.input.txt
```

```
cnofs_test.Ephem.input.txt
```

View the contents of these files, and compare their parameters to the selections on the GUI panels, and referencing the User's Guide keyword/value parameter charts:

*cnofs\_test.Ephem.input.txt*

shows the specified propagator, TLE file, the start/stop time, time step from the satellite tab (the Kepler 'Use J2' parameter defaults to 'true' and therefore not required to be in the input file); the time, coordinate and delimiter specifications from the Advanced Options dialog are seen in the input file, as is the Number of processors (the negative number indicates to *not* 'verify HW'). The name of the generated ephemeris file, based upon the input TLE filename, is also shown.

*cnofs\_test.AP9.input.txt* shows the model name 'AP9', the proton species via the ModelDB specification, Differential flux, the list of proton energies; the 'perturbed' flux option, for 40 scenarios, and standard aggregation confidence levels of 50, 75 and 95; the additional 85 is specified on a separate line. The output file prefix is constructed from the specified 'Run Name' and particle species. The accumulation interval is shown as 600 seconds. The OrbitFile parameter specifies the ephemeris file that was generated by the 'Ephem' model run. The input file also shows the time, coordinate and delimiter specifications, and number of processors, from the Advance Options dialog. Because the 'Generate Geomag/Adiabatic' checkbox was

checked, the 'AdiabatOut: True' parameter is present, but only in this model run input file – these results are model independent, and therefore only need to be calculated once. The specified options for the ShieldDose2 model parameters are also shown: depth values and units, detector, geometry and attenuation mode.

*cnofs\_test.AE9.input.txt* is nearly identical to its proton counterpart, save the model name, ModelDB specification, energy list, and output file prefix.

#### *Application and Utility Execution*

For this case, pushing the 'run' button in the GUI invokes the execution of the 'CmdLineAe9Ap9' application three times, and a subsequent execution of the TotalDose post-processing utility application. This series of executions generates one ephemeris file, and a total of 289 model results files (*ls cnofs\_test\*output\*.txt | wc -l*). The presence of these files indicates the proper execution of these applications. Notable files included in this collection include:

ephem\_cnofs\_tle.dat – the generated ephemeris file  
*cnofs\_test.\*.output\_mc\_flux\_???.txt* – 40 files, 2 sets (AE9 & AP9) of 20 scenario files each  
*cnofs\_test.\*.output\_mc\_flux\_conf\_level\_???.txt* – 8 files, 2 sets of 4 confidence levels (50, 75, 95 and the additional 99)  
*cnofs\_test.AE9.output\_adiabat.txt* – the generated adiabatic invariant coordinates  
*cnofs\_test.AE9.output\_mc\_Totaldose\*.txt* – 48 files of 'total dose' that combine the electron and proton dose results; their presence indicates the proper execution of the 'TotalDose' utility application by the GUI.

#### *Plot Generation*

In the GUI, switch to the Plot tab

When 'Run Name' shows 'cnofs\_test', the model list should show both Plasma models and AE9/AP9; the Shield Depths list show the full set of depth values (though presently inactive), and the 'Dose Rate' and 'Dose Accum' selections are active (if either are selected, the depths list will become active). Under the 'other' box for the Confidence Levels, it should report '99' as being available, and the 'Scenarios' box show 1-20 as being available.

Select 'Dose Rate', then check the 'All' checkbox under the Shield Depths list; select 'Thickness' under X-Axis quantity. Check the 'Electron Dose' and 'Proton Dose', and 'X-log'. Check the '50%' under Confidence Levels. Enter '660' (minutes) in the Time Selection box, press 'Plot'. In a terminal window, look for the most recent file named in the form '*cnofs\_test\_Plot\_???.txt*', and view the file, comparing the numeric values to the plot.

Also view the files '*cnofs\_test.A?9.output\_mc\_\*doserateIntvAvg\_conf\_level\_50.txt*' – this will be the electron, proton and total dose rate output files from which these values are extracted for plotting. The time value of '660 minutes' is in reference to the start time of the ephemeris (the input file '*cnofs\_test.Ephem.input.txt*

' shows the start time as 2011, 5, 30, 2, 20, 24); adding 660 minutes (11 hours) to the that gives 5, 30, 13, 20, 24. Using this time as a reference in the three files, the dose rate values on the lines should match those shown in the generated file associated with the plot.

Use case 3:

Sat Tab:

Orbit Specification Type: select Ephemeris File

Input File: ../../samples/OrbitSample.dat

Time Format: Year DDD Gmtsec

Coordinate system: GEI, Re

Data Delimiter: comma

Press 'Set'

Model Tab:

Run Name: 'extern\_test'

Model: AE9/AP9

Model Mode: Mean

Flux type: Differential

unchecked 'include Plasma Energy Levels'

unchecked 'Compute Dose'

select energies 0.04 through 6.00 MeV in Electrons

select energies 0.10 through 150 Mev in Protons

set 'Accum Interval' to 0 seconds

Press 'Advanced Options':

unchecked 'Calculate Omnidirectional Flux'

Enter '90,80,70' in Pitch Angles

unchecked 'Generate Geomag/Adiabatic Output File'

check 75<sup>th</sup> percentile

add '85' in 'Other Percentiles'

set Number of Proc to 1

set Time Format to 'Modified Julian Date'

set Coordinate System to 'RLL', 'km'

check 'Inverted Order' checkbox

set Data Delimiter to 'Tab'

(press Close)

press 'Run'

(GUI controls will become 'grayed-out', and the progress bar will show the current status.

<(this run will take less than a minute)>

At the conclusion of the run, the GUI controls will return to normal. Leave it running, as the current settings will be referenced in when reviewing the generated files.

In a separate terminal window, navigate to the 'Run' directory, and enter the command

ls extern\_test\*input.txt

Two files should be listed, representing the inputs for two separate model runs performed by the GUI application (since an external ephemeris file is used, no 'ephem' run is needed).

extern\_test.AE9.input.txt

extern\_test.AP9.input.txt

View the contents of these files, and compare their parameters to the selections on the GUI panels, and referencing the User's Guide keyword/value parameter charts:

*extern\_test.AP9.input.txt* shows the model name 'AP9', the proton species via the ModelDB specification, Differential flux, the specific list of proton energies [0.1-150]; the 'mean' flux option, the additional 75 and 85 percentiles are specified on a separate line. The specific pitch angles are also listed. The output file prefix is constructed from the specified 'Run Name' and particle species. The OrbitFile parameter shows the ephemeris file that was specified, with its associated 'input' specifications (preceded by "In") for time [YrDddGmt], coordinate system [GEI,Re] and data delimiter[comma]. The 'output' specifications are also shown for time [MJD], coordinate system [RLL,km,inverted] and delimiter [tab] from the Advanced Options dialog.

*extern\_test.AE9.input.txt* is nearly identical to its proton counterpart, save the model name, ModelDB specification, specific energy list [0.04-6], and output file prefix.

#### *Application and Utility Execution*

For this case, pushing the 'run' button in the GUI invokes the execution of the 'CmdLineAe9Ap9' application two times. This series of executions generates a total of 12 model results files (`ls extern_test*output*.txt | wc -l`). The presence of these files indicates the proper execution of these applications.

Viewing any of these files, observe that the header information indicates the requested pitch angles, proper energy list for the particle, and the time and coordinate specifications. Also note the appropriate data column headers are present, and the values for time and coordinates are in the requested form and ordering. For these multiple pitch angles, lines are repeated contain the same time and coordinates, but are for different pitch angles.

#### *Plot Generation*

In the GUI, switch to the Plot tab

When 'Run Name' shows 'extern\_test', the model list should show the AE9/AP9; the Electron and Proton energy lists only show those levels requested. The Model Percentiles should only show Mean and 75<sup>th</sup> as active checkboxes, the 'other' box should report '85' as being available. The Pitch Angle drop-down box will show '90', and also have '80' and '70' as choices.

Select 0.10 in the Electrons list, 0.60 in the Protons list. Under Model Percentiles, uncheck 'Mean', check '75<sup>th</sup>'. Select Pitch Angle '80', and 'Plot'. In a terminal window, look for the most recent file named in the form 'extern\_test\_Plot\_???.txt', and view the file, comparing the numeric values to the plot.

Also view the files 'extern\_test.A?9.output\_pctile\_flux\_75.txt' – this will be the electron and proton flux output files from which these values are extracted for plotting. Examine the values in the 3<sup>rd</sup> data column after the pitch angle in the electron file, and 4<sup>th</sup> column in the proton file. Starting from the second data line (where pitch angle=80), and then every third line (skipping the values for the other two pitch angles) after that, these values will match those in the generated plot file.