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IRENE V1.57 Feature Changes

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IRENE – International Radiation Environment Near Earth

- IRENE is both a *geophysical model* and a *software suite* for the calculation of various relevant satellite environment parameters and effects through the use of multiple model components.
- Currently, the geophysical model covers ‘trapped’ radiation belt and plasma particles; in the near future, it will also incorporate models for other sources of particle fluxes, such as untrapped solar particles, and the software suite will add other effects calculations.
- The change in the package name from the original ‘Ae9/Ap9’ to ‘IRENE’ reflects this expansion of scope and the addition of new collaborating partners in the overall package development.

IRENE – International Radiation Environment Near Earth

- The IRENE model package is hosted at https://www.vdl.afrl.af.mil/programs/ae9ap9 .
  - This public site includes both general and detailed information about the IRENE model collection, as well as instructions for obtaining the current model software.
- The development of the IRENE software is on-going (since ~2008).
  - New features and capabilities are always being added.
  - Existing features are being improved and optimized when possible.
- Updates of specific features of the software since the *Ae9Ap9 v1.50* release (2017) will be highlighted within the following overview slides.
- **We welcome all suggestions for improvements and/or new capabilities to be included in future versions of the IRENE package**.

IRENE Software Suite Overview

Several ways to perform various satellite environment calculations

Most include parallelized processing capabilities

- Graphical User Interface application
  - User-friendly interface for defining the various satellite and model parameters, executing the model run, and inspection of the results in limited plotting features.
  - Front-end to the Command-line application.
- Command-line application
  - Execution uses a user-constructed input file with parameter specifications.
  - Produces output files of the requested calculation results.
- Application Programming Interface
  - Available for use with C++, C and Python language programs/scripts.
  - Enables programmatic driving of the application and access to those results.
  - Provides a direct interface to each of the various underlying component models.

IRENE Software Call Stack

Graphical User Interface Application

User-friendly access for execution of AE9/AP9 and other models, with basic graphical outputs

Command-Line Application

Input-file driven execution of AE9/AP9 and other models; can be run in batch mode, or set up with scripts

Application-Level API

- C++ interface for specification of model run parameters, output file generation and access to results
- C and Python interfaces are also available
- Features parallelized processing capabilities for most types of calculations
- Ephemeris generation using choice of orbit propagators
- Several modes for flux calculations using AE9/AP9/SPM models
- Flux calculations using legacy models (e.g. AP8/AE8, CRRES)
- Accumulates flux results over time in multiple modes (cumulative, interval, full, boxcar, exponential)
- Calculates dose rate and accumulated dose values from fluxes
- Aggregates flux/fluence/dose results from sets of 'Perturbed Mean' or 'Monte Carlo' scenario outputs

Scheduler

Determines model processing units needed for performing requested calculation, and coordinates parallelization

Model-Level API

C++ interfaces to each of the component model processing units; C and Python interfaces are also available.

Ephemeris	Ae9/Ap9	Accumulation	Dose	Aggregation	Legacy

Supporting Models

- Orbit Propagation
- Magnetic Field
- Coordinate conversions
- Adiabatic Invariant Coordinates
- ShieldDose2 / Dose Kernel
- Legacy Radiation Belt models

Lower-level Utilities

- Database access utilities
- MPI, Boost and HDF5 third-party libraries
- System libraries

IRENE Software Suite Distribution

Release distribution is in the form of a zipfile.

Hosted at https://www.vdl.afrl.af.mil/programs/ae9ap9

- 'base' distribution
  - Contains precompiled Windows binaries and libraries, model databases, sample input and output files, and supporting documentation.
- 'source' distribution - *available upon request*
  - Contains all above, plus source code files.

The IRENE software package is currently 'officially' supported on:

- Windows 10
  - Simply unzip to install; some MS libraries may need to be installed.
- RedHat/CentOS/Rocky 7.x, 8.x, and Ubuntu 20.4 Linux flavors
  - Requires the 'source' distribution for installation.
  - Use on other similar/derivative Linux flavors is likely possible.

IRENE Software Suite Documentation

- **Release Notes –** highlights new/changed features and capabilities.
- **Build Instructions –** primarily needed for installation on Linux systems.
  - Describes the necessary system prerequisites, build process and testing procedures.
  - Entire build process was significantly improved since v1.50.
  - Linux builds now rely on system-installed packages for third-party library dependencies (no manual builds of these are required).
- **User's Guide –** describes overall software suite setup, features and capabilities.
  - Detailed information for using Command-line and GUI applications.
  - Appendices contain supporting information, testing instructions, trouble-shooting and additional installation tips (ie, use of common installation location).
- **C++ API –** describes the C++ programmatic interfaces.
- **C API –** describes the C programmatic interfaces.
- **Python API –** describes the Python programmatic interfaces.
- **Known Issues –** describes assumptions, deficiencies and caveats.

IRENE Software Application Features and Options

Command-Line Application: “CmdLineIrene”

- Invoked from a command-line terminal window.
- Uses a user-constructed ASCII input file.
  - All parameter specifications are in a ‘key/value’ format.
  - Each of these parameters are fully described in *User’s Guide.*
- Produces a set of output files of calculation results.
  - Number of files generated and their data results contents are defined by the various user specifications and data selections.

IRENE Software Application Features and Options (continued)

- Satellite Position Specification Options:
  - Two-Line Element file, set of orbital elements, or state vectors.
    - Multiple orbit propagator models available.
  - User-supplied file containing satellite ephemeris, or a *grid of positions.*
    - Several time formats and coordinate systems are supported.
    - Variable ephemeris timesteps are allowed.
  - Optional pitch angle or direction vector inputs.
  - Optional output of the associated Adiabatic Invariant/Magnetic field values.

Coordinate Systems		Time Formats
Geocentric Earth Inertial	Solar Magnetic	Modified Julian Date (Ref = 17 Nov 1858)
Geocentric Cartesian	Magnetic (tilted dipole)	Year, DayOfYear+fraction
Geodetic (WGS84)	Spherical	Year, DayOfYear, Gmtsec
Geocentric Solar Magnetospheric	Radius, Latitude, Longitude	Year, Month, Day, Gmtsec
Geocentric Solar Ecliptic		Year, Month, Day, Hr, Min, Sec

IRENE Software Application Features and Options (continued)

- Particle Flux Calculation Options
  - Flux models (particle flux):
    - AE9 / AP9
    - SPM (Space Plasma Model) – lower energy levels
    - Legacy models – only supports ‘Mean’ flux mode
      - AE8 / AP8
      - CRRESELE / CRRESPRO
      - CAMMICE
  - Flux modes:
    - Mean
    - Percentile
    - Perturbed Mean (up to 999 scenarios)
    - Monte Carlo (up to 999 scenarios)

IRENE Software Application Features and Options (continued)

- Further Processing Options
  - Accumulation modes (flux average, fluence):
    - Cumulative
    - Interval
    - Boxcar Flux Average (running average)
    - Exponential Flux Average
    - Full (single value reported for entire mission)
  - Accumulation special features:
    - Multiple time windows (up to nine) may be specified concurrently for Interval, Boxcar and Exponential modes.
    - Custom report times may be defined for Boxcar and Exponential modes.
    - Worst Case (to date) values can be reported for Boxcar and Exponential Flux Average *Monte Carlo* results, and separate log files generated when requested.

IRENE Software Accumulation New Special Feature Details

- Multiple concurrent Accumulation time intervals
  - Useful in support of SEE assessment and/or analysis.
  - Tracking of internal charging bleed-off from different materials.
- Worst Case tracking and log files
  - Works with Monte Carlo Boxcar and/or Exponential Flux Averages.
  - Generates Confidence Levels when in Monte Carlo mode.
  - Supports calculations/analysis for SEE and internal charging.
  - Log files may be used to find a particular worst case, and examine the actual fluxes from that date and MC scenario.
  - This feature was implemented in IRENE at the suggestion of NASA, in support of their Lunar Gateway work.

IRENE Software Application Features and Options (continued)

- Dose Calculations (dose rate, dose accumulations)
  - ShieldDose2 model
    - Bugfix of C++ code, with significantly improved performance.
    - Geometry specifications:
      - Spherical4pi – new explicit definition for *full* sphere
      - Spherical2pi – formerly ambiguous 'spherical'
      - Finite Slab
      - Semi-Infinite Slab
    - Dose Detector
      - Standard list of materials
    - List of Depth values
  - Dose Kernel – new feature; more details in Paul's presentation.
    - Kernel = matrix representing a linear transformation.
    - Alternate method for dose calculation, based on ShieldDose2 results.
    - Uses same input parameters as ShieldDose2.
    - Somewhat faster than ShieldDose2, produces slightly differing results.

IRENE Software Application Features and Options (continued)

- Aggregation
  - Produces statistical ‘confidence level’ percent values.
  - Calculated (at each timestep) from the collection of ‘Perturbed Mean’ and/or ‘Monte Carlo’ scenario results.
  - Percent of 0 or 100 return the minimum or maximum scenario values.

- Post-Processing Utilities
  - Combines results from separate IRENE model runs (each run is for single model and/or particle type).
    - Summation of electron and proton dose results.
    - Adjustment of SPM results for ‘integral’ flux results.

IRENE Software Application Features and Options (continued)

- Output control parameters:
  - Specify coordinate system of ephemeris positions reported in all output files.
    - Regardless of input ephemeris type (supplied or generated).
  - Specify production of results output files in ASCII (default) and/or binary form.
  - Limitation of ASCII file generation
    - According to model parameters and processing options selected, many hundreds or thousands of files could be produced.
    - Types of ASCII output files can be selectively defined.
  - Specify time format and data delimiter used in ASCII output files.
- Processing performance tuning:
  - Specify ‘chunk’ sizing – revised default to ‘sweet spot’ of optimal performance.
  - Alternate work directory for more efficient I/O of temporary files.
  - Multi-threaded executions
    - Multiple processors in a single computer system, or in a cluster.
    - Supported on both Linux and Windows.
    - Additional setting required on Windows with an active VPN connection, due to issues with Intel MPI library.
    - Use of ‘hyperthreads’ in processor count negatively affects performance.

IRENE Software Application Execution and Outputs

Model Run Execution

`CmdLineIrene -i` <*input_filename*> [*options*]

- The input file is parsed, and the various parameter settings validated.
- Any errors and/or incompatibilities are flagged, providing informative messages about the problem.
- A rough progress updates are shown during the various model calculation segments.
- Because these model runs are currently limited to a single species (ie electron vs proton), multiple runs may be necessary to fully complete the desired calculations.
- Execution of the post-processing utilities may be needed for combining the results of certain types of outputs from different model runs.

Output Files – produced according to input parameter selections (including name and location).

- Generated Ephemeris.
- Adiabatic Invariant and Magnetic field info.
- 'Raw' particle Flux levels at each ephemeris position / percentile / scenario.
- Accumulation flux averages and/or fluences / percentile / scenario.
- Dose rate at each ephemeris position / percentile / scenario.
- Dose accumulations / percentile / scenario.
- Aggregation Confidence Level results for flux, fluences, dose rates and/or dose accumulations.
- Worst Case Boxcar and/or Exponential Flux Average results, associated log files.

IRENE Software Application Output File Naming

- The various output files are produced in the specified directory location.
- Each file is named using the specified run identifier (“Prefix”) and the particular modifiers that properly identify each data output type, using the file-naming scheme below.
- IRENE includes a Python utility script to convert ASCII output files to Excel format files.

Prefix	Data Mode based on <FluxOut> value	Data Type	Percentile, Scenario and/or Aggregation Id, based on <FluxOut> and <Aggregate> values	Suffix
<OutFile> (without the filename extension, ie ‘.txt’)	_mean	Based on <*Out> and AccumMode values. *See the table below*	(-n/a- for mean)	filename extension of <OutFile> or ‘.txt’ if not included
	_pctile		_## (percentile, in <FluxOut> value)	
	_pert _mc | mcWC (worst case)		_### (scenario identification #) _conf_level_##	

AccumMode DataType	*Cumul*	*Interval* (for multiple intervals, #2-9 is appended to ‘Intv’)	*Full*	*Boxcar* (for mult intervals, #2-9 is appended to ‘Run’)	*Expon* (for mult intervals, #2-9 is appended to ‘Exp’)
Flux	_flux	_fluxIntvAvg	_fluxFullAvg	_fluxRunAvg	_fluxExpAvg
Fluence	_fluence	_fluenceIntv	_fluenceFull	- - - - - - -	- - - - - - -
DoseRate	_doserate	_doserateIntvAvg	_doserateFullAvg	- - - - - - -	- - - - - - -
DoseAccum	_doseaccum	_doseaccumIntv	_doseaccumFull	- - - - - - -	- - - - - - -

IRENE Software GUI Application Features and Options

Graphical User Interface Application: “IreneGui”

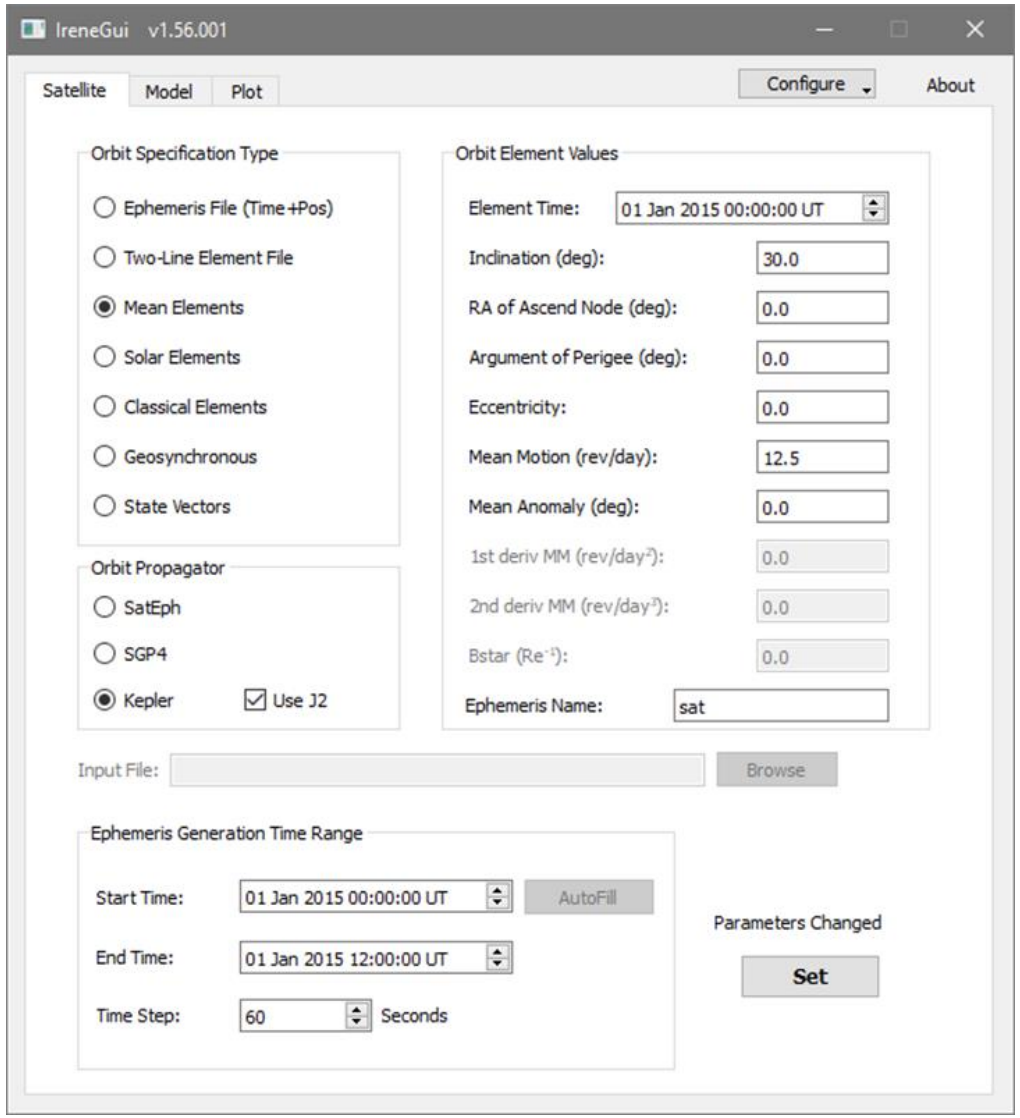
- A user-friendly graphical user interface for the IRENE model.
  - Based on the selections and specifications made by the user, the appropriate model run input files are generated.
  - Internally, the CmdLineIrene application is invoked for each input file.
  - Any necessary post-processing is also automatically performed.
- Produces a full set of ASCII output files of various calculation results.
  - Number of files generated and their data results contents are defined by the various user specifications and selections.
  - Basic plots of these results may be produced from these files.
- The GUI controls are divided into three tabbed pages:
  - ‘Satellite’, ‘Model’ and ‘Plot’.
  - This follows the typical progression of a model run session.

IRENE Software GUI Application Features and Options (continued)

‘Satellite’ Tab

A satellite’s orbital path can be specified in several different ways:

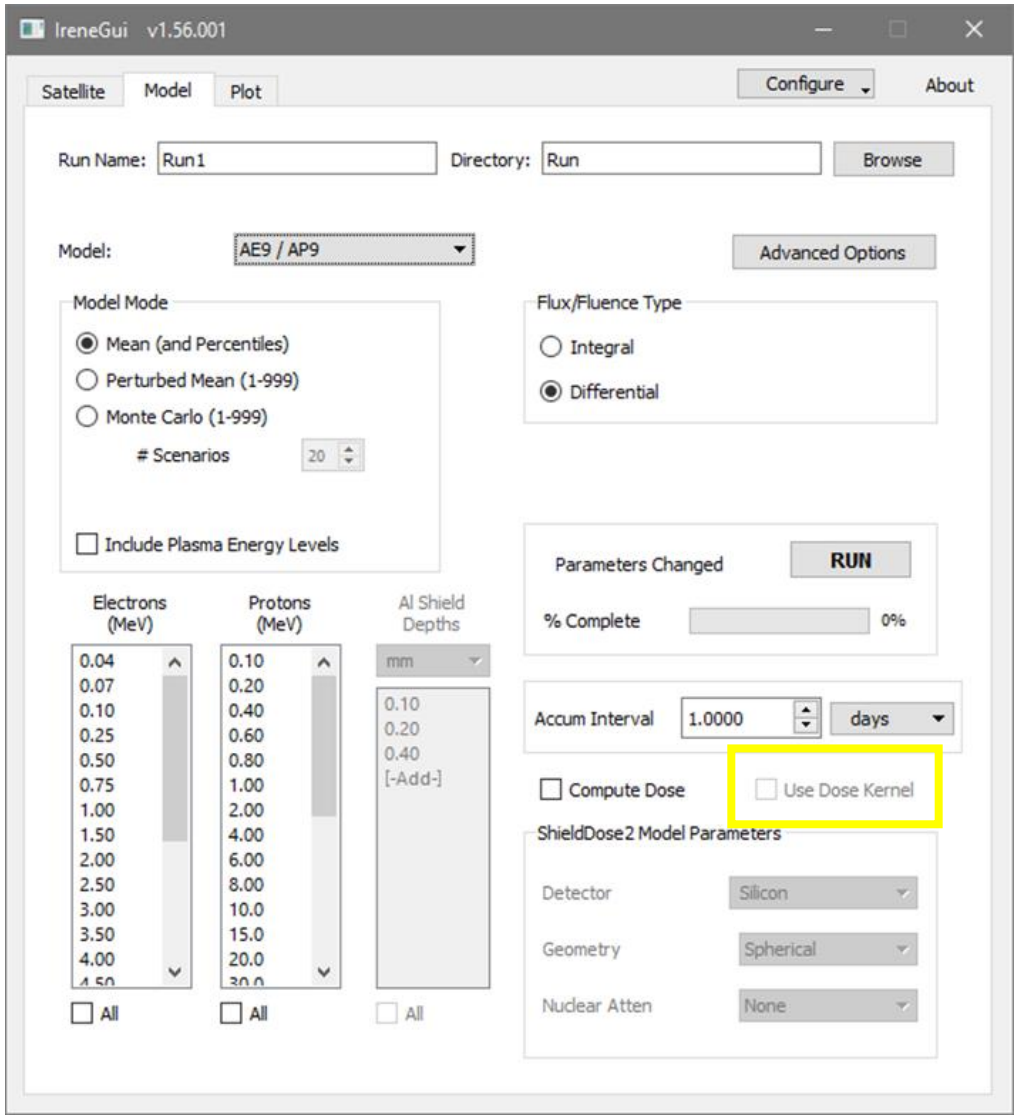
- The right-hand column of input fields changes according to the input type selected.
- For an external input ephemeris file, other selections are needed to define the time format and coordinate system being used.



IRENE Software GUI Application Features and Options (continued)

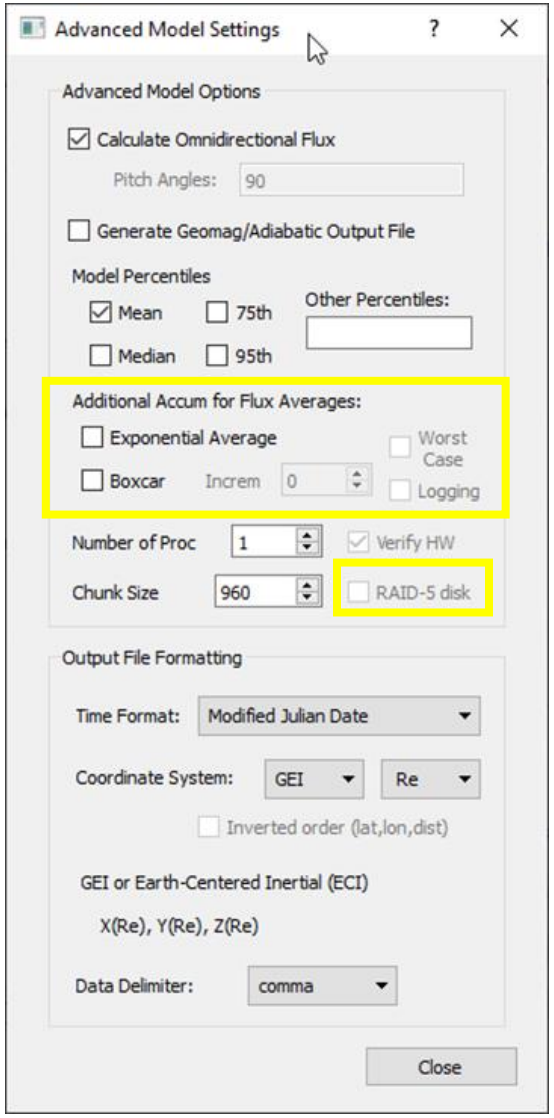
‘Model’ Tab

The desired models and their relevant settings and selections are defined here and the ‘Advanced Options’ dialog window.



IRENE Software GUI Application Features and Options (continued)

The 'Advanced Options' button shows a dialog with more settings, some of them are model and/or mode-specific.



Also includes ASCII output file options:

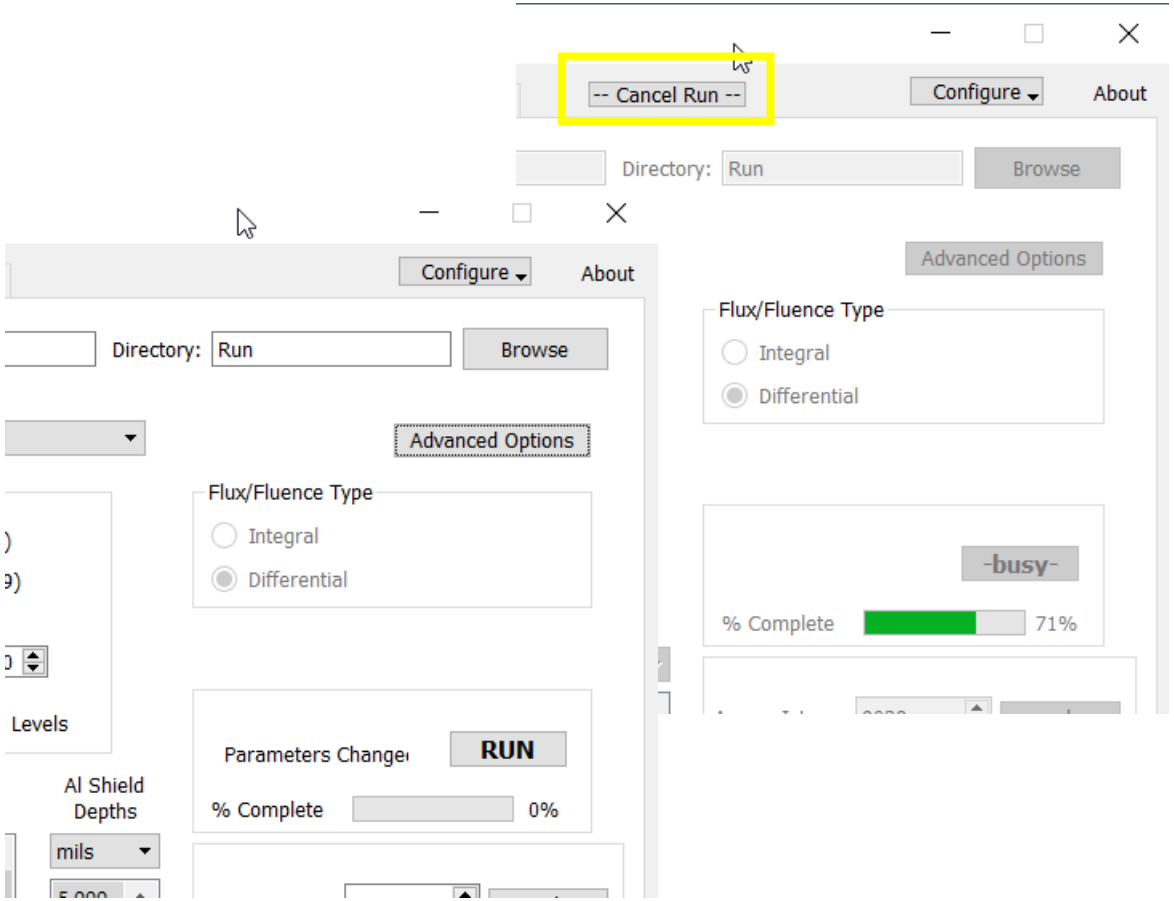
- Time format
- Coordinate system and units
- Data delimiter

The GUI application supports *most* of the settings available within the CmdLineIrene application.

However, some of the more advanced/complicated features, such as the multiple accumulation interval definitions, are not currently possible.

IRENE Software GUI Application Features and Options (continued)

- Pressing the ‘RUN’ button invokes the model run processing.
- The various user specifications and settings are checked for errors and/or incompatibilities.
  - Informative error messages are shown when necessary.
- A progress bar provides a rough estimate of the completion of all the requested model calculations.
- During the processing, a ‘Cancel’ button is available at the top edge, allowing a graceful way to halt.

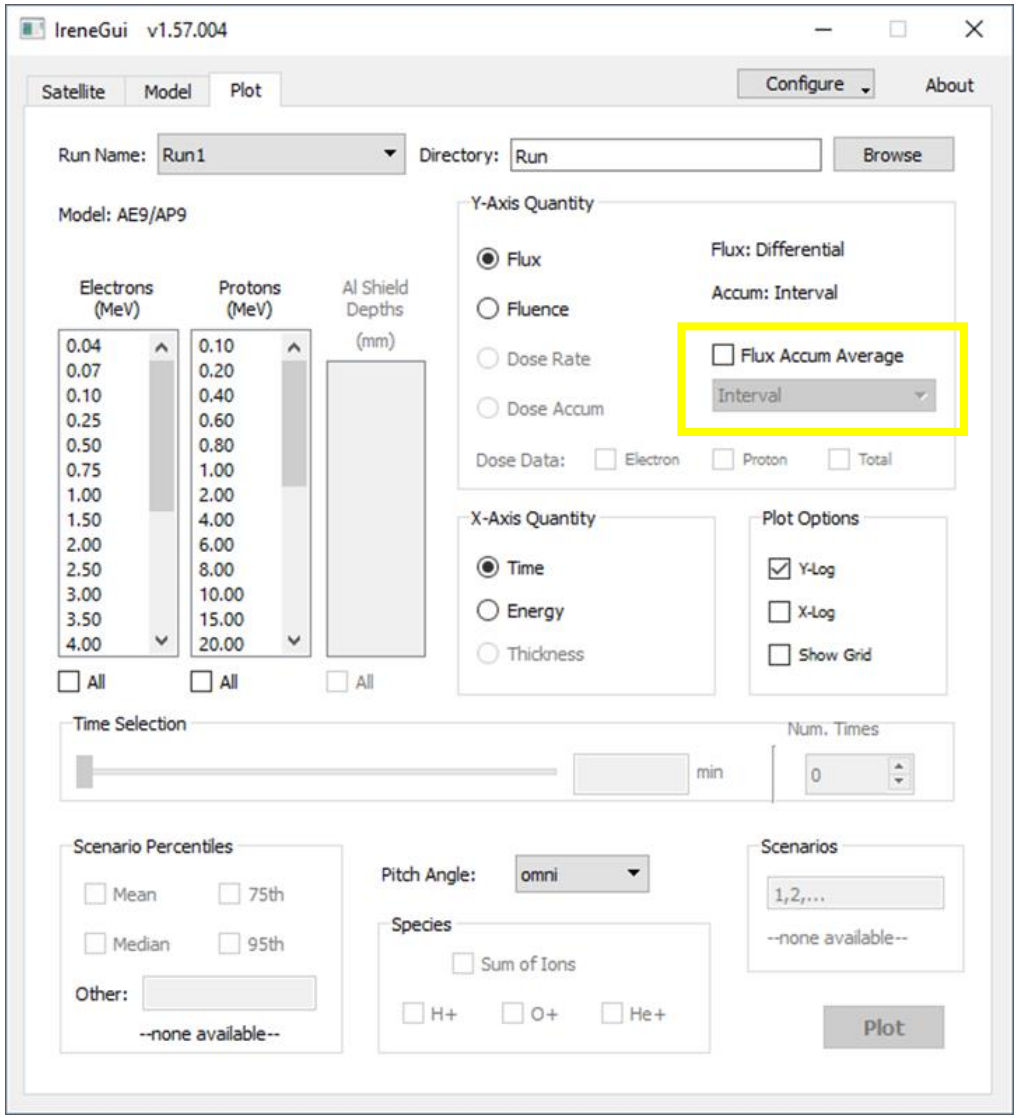


IRENE Software GUI Application Features and Options (continued)

‘Plot’ Tab

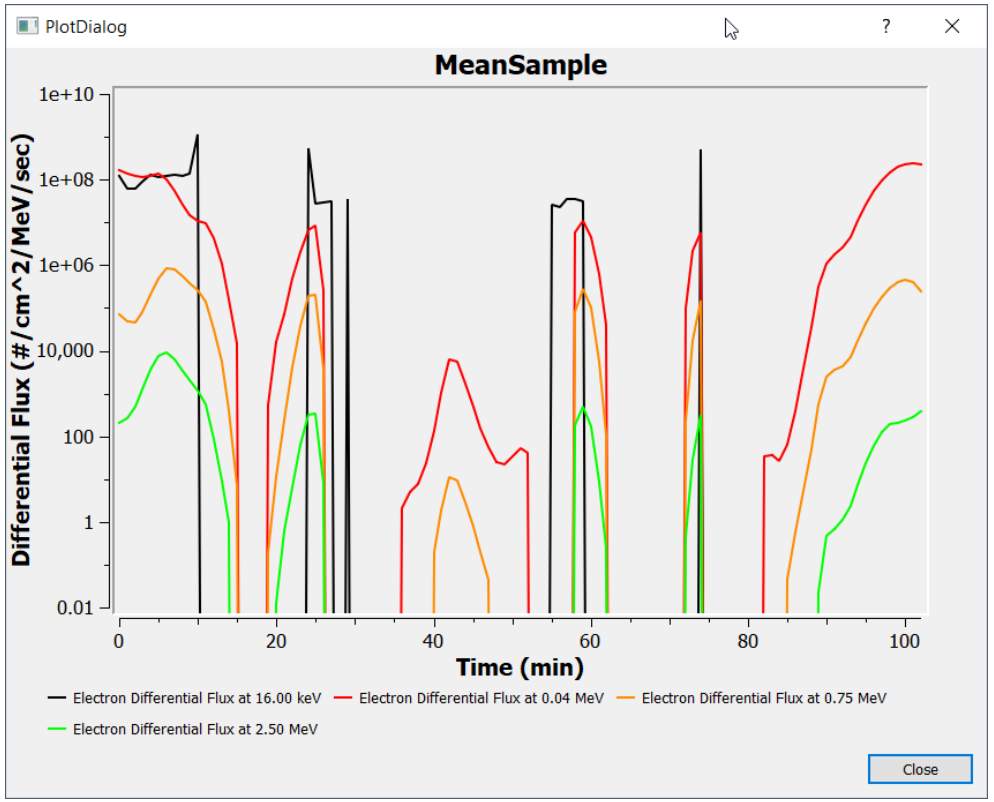
Provides an interface for producing *basic* 2-D plots of the model calculation results. Recent updates enable the plotting of the various flux average accumulation types.

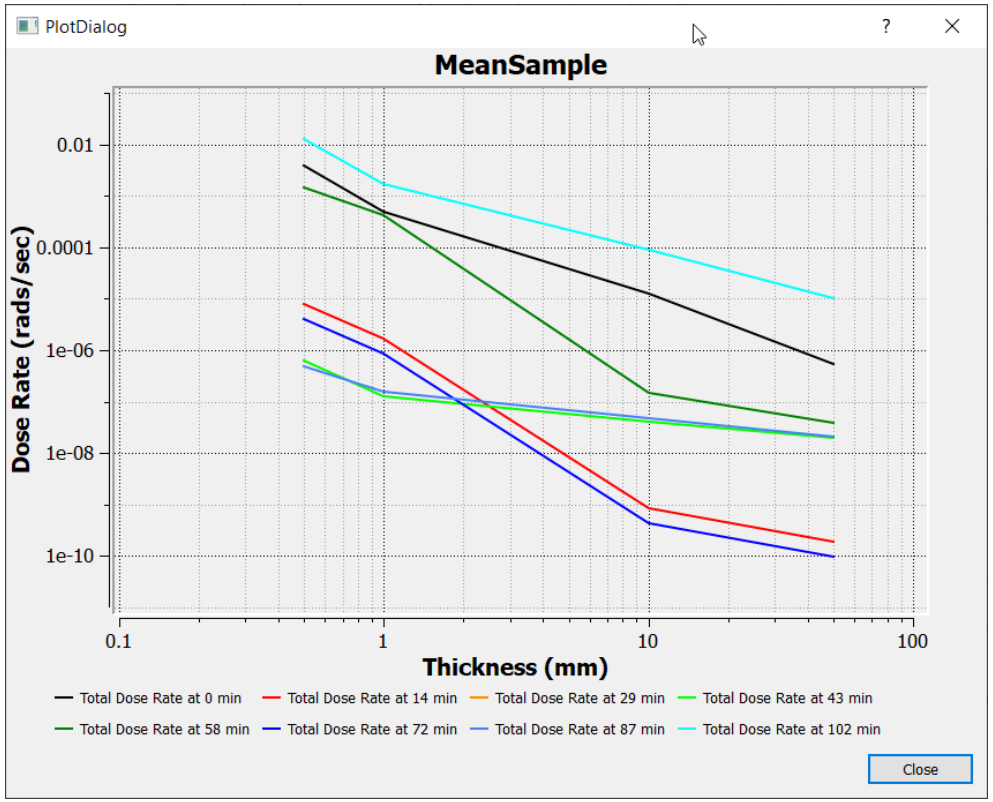
A variety of plot types can be produced from the current model run results, or from any previously completed runs, as identified by the ‘*Run Name*’. There are only limited options available (ie no zooming), but all plot data is automatically written to files; these could be used by other applications.



IRENE Software GUI Application Features and Options (continued)

Sample plots





IRENE Software Application Programming Interface (API)

Interfaces for C++, C and Python user applications, at two levels:

- “Application Level”
  - Programmatically construct set of inputs to the Command-Line application
  - Execute model run (including parallelization).
  - Access the various types of results.
- “Model Level”
  - Directly interface with each of the underlying component model units.
  - DateTimeUtil, Ephemeris, CoordConv, Adiabat, Ae9Ap9, Accumulation, Dose, DoseKernel, Aggregation, Radenv(legacy), Cammice(legacy).
  - Requires careful attention to inputs, as less error-checking possible.
  - No parallelization capabilities available at this level.

Full descriptions of the many classes and methods in both API levels are available in their respective language API documents.

IRENE Software Application Programming Interface (continued)

To assist in the development of IRENE-interfacing user applications, the distribution includes a set of API demonstration programs/scripts, for both API levels in all three languages.

The IRENE source code is primarily C++. The C API is a wrapper on the C++ code, and the Python API is in turn a wrapper on the C API.

Python script usage may require setting of environment variables for its proper coordination with the underlying IRENE C++ libraries.

→ Be aware that the IRENE Python API is not fully “Pythonic”, in the sense that when an error occurs, an error code is *returned*, instead of throwing an exception. This is largely due to the very nature of these Python methods, simply wrapping the base-level C++ methods and their error handling.

The API will be discussed further during the IRENE software demo / Q&A session.

IRENE Software Suite Support

Questions about the model and software suite, its use or errors?

- Extensive Documentation
  - Hoped to be as comprehensive as possible.
  - Still being improved and expanded when questions arise.
- Email support
  - Bob Johnston, Air Force Research Laboratory, AFRL.RVBXR.AE9.AP9.Org.Mbx@us.af.mil
  - Paul O'Brien, The Aerospace Corporation, paul.obrien@aero.org
- Right now ---

- **We welcome all suggestions for improvements and/or new capabilities to be included in future versions of the IRENE package.**

IRENE Software Class Diagram (for reference; from User's Guide)