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AE8/AP8 IMPLEMENTATIONS IN AE9/AP9, IRBEM, AND SPENVIS

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Technical Report

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14. ABSTRACT
This report describes validation results for the AE8/AP8 legacy models as implemented in the AE9/AP9/SPM architecture in comparison to AE8/AP8 as implemented in the SPENVIS and IRBEM tools. The CmdlineAe9Ap9, SPENVIS and IRBEM implementations of the AE8/AP8 and SHIELDOSE2 models were used with a GTO satellite ephemeris for 10 full orbits, for the calculation of electron and proton integral and differential flux values, and their associated dose values for the three defined geometries. The flux values and dose results from these three implementations closely match with the recent revisions of the CmdlineAe9Ap9 (included in V1.05) and IRBEM library. Some small differences are observed, but can be attributed to differences in the magnetic field models and AE8/AP8 model settings, and for dose results to differences in the SHIELDOSE2 processing settings.

15. SUBJECT TERMS
AE9/AP9/SPM, radiation belt model, SHIELDOSE, AE8/AP8

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AE8/AP8 Implementations in AE9/AP9, IRBEM, and SPENVIS

The CmdlineAe9Ap9, SPENVIS and IRBEM implementations of the AE8/AP8 and SHIELDOSE2 models were used with a GTO satellite ephemeris for 10 full orbits, for the calculation of electron and proton integral and differential flux values, and their associated dose values for the three defined geometries. The flux values and dose results from these three implementations closely match, with the recent revisions of the CmdlineAe9Ap9 (included in V1.1) and IRBEM library (to be included in a 2013 release). Some small differences are observed, but can be attributed to differences in the magnetic field models and AE8/AP8 model settings, and for dose results to differences in the SHIELDOSE2 processing settings.

1. Introduction

This document provides a comparison of results from the AE8/AP8 model implemented within the AE9/AP9 model application (CmdLineAe9Ap9), IRBEM (previously called ONERA) and SPENVIS. Results for time-average fluxes and total dose calculations via SHIELDOSE2 are provided. The ephemeris for 10 full orbits of a Geosynchronous Transfer Orbit (GTO) is used for this comparison, as it samples a wide range of locations within the radiation belts. The new AE9/AP9 model application includes the ability to query the legacy AE8 and AP8 models. The AE8 and AP8 flux and dose results from this show some differences when compared to those from the IRBEM and SPENVIS implementations. For reference, the AE9/AP9/SPM model is described by *Ginet et al.* [2013] and *Roth et al.* [2014], AP-8 by *Sawyer and Vette* [1976], AE-8 by *Vette* [1991], and SHIELDOSE2 by *Seltzer* [1994].

2. Generation of Model Results

The Ae9Ap9 package GUI program was used to generate ephemeris information, and perform AE8/AP8 and SHIELDOSE2 model runs via the CmdLineAe9Ap9 application. The AE8/AP8 model is run for solar maximum, with SAA translation. SHIELDOSE2 model parameters are listed below. An external script processed the time-tagged results to produce the sets of average integral and differential flux values as a function of energy, for comparison to the SPENVIS output products.

The information in the CmdLineAe9Ap9-generated ephemeris file was processed by an external script to produce a file in the format expected by the SPENVIS web-based system; most importantly, this script converted the original Modified Julian Date time values to the alternate definition used by SPENVIS. This ephemeris file was processed by the SPENVIS system to generate the AE8/AP8 [solar max] integral and differential flux values, and associated SHIELDOSE2 model dose results (using the same model parameters listed below).

The generated ephemeris file was also used as input to a program interfacing with the IRBEM library implementations of the AE8/AP8 models and the SHIELDOSE2 model. External scripts were used to produce sets of the average flux values as a function of energy.

For a secondary comparison, the CmdLineAe9Ap9 application was also used to produce an equivalent set of flux and dose output files from the AE9 and AP9 models, with these results included in the comparison plots here for reference. Results from AE9 and AP9 are generally somewhat different from results from the various AE8 and AP8 implementations. This is to be expected, given that the AE9/AP9 models use new datasets covering a longer time period than prior models, and are processed in a novel architecture providing additional capabilities. The AE9 and AP9 results shown are for a specific time period and type of orbit, and may have a very different character in relation to the AE8 and AP8 results for other time periods and/or orbit types. These AE9/AP9 results are from "Mean" mode model runs only. The results from "Perturbed Mean" or "Monte-Carlo" mode model runs will also differ, as these modes incorporate the uncertainties due to measurement errors and (for Monte-Carlo only) estimates of the dynamic variations due to space weather processes. For more discussion of AE9/AP9 datasets and architecture, and the resulting differences from AE8/AP8, see *Ginet et al.* [2013].

3. Model Run Parameters Used in This Comparison

Orbital Ephemeris:

- Geosynchronous Transfer Orbit (GTO): 180×35870 km, inclination=6°, period=37922 seconds.
  Eccentricit 0.7314 4, MeanMotion 2.27 3 0 or its da , and 0.0
- Duration/Rate 10 or its, at t 37 sec, 100 points per or it.
- Time period: 01 Jan 2013 0000UT – 05 Jan 2013 0921 UT (4.386 days) [arbitrarily chosen] (Note: this time period applies to orbit generation only; AE8/AP8 utilizes geomagnetic field models from other epochs as specified in the table below.)

SHIELDOSE2 model:

- Materials: aluminum shielding; silicon detector
- Dose depths: 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.8, 1, 1.5, 2, 2.5, 3, 4, 5, 6, 7, 8, 9, 10, 12, 14, 16, 18, 20 mm
- Geometries: Spherical, Finite Slab, Semi-Infinite Slab
- Nuclear attenuation: none

4. Discussion of Differences between Model Implementations

Differences between the results from CmdLineAe9Ap9, IRBEM and SPENVIS are generally less than 5-40%. These differences are due to several issues:

- The magnetic field models for the implementations are different, as summarized in Table 1. Neither IRBEM nor SPENVIS use an external field model. Most of the differences in fluxes are explained by the differences in the default internal field model. With appropriate advanced settings in AE8/AP8, the IGRF field model closely matches the Jensen and Cain field model and consequently output fluxes are very similar. The lack of an external field in SPENVIS and IRBEM can result in significant differences at high L-values.

Table 1

Application	AE8MIN	AE8MAX	AP8MIN	AP8MAX
SPENVIS	Jensen and Cain	Jensen and Cain	Jensen and Cain	GSFC 12/66, updated to 1970
IRBEM	Jensen and Cain	Jensen and Cain	Jensen and Cain	GSFC 12/66, updated to 1970
CmdLine Ae9Ap9	IGRF @ date/1962 *Ext:* Olsen-Pfitzer	IGRF @ date/1962 *Ext:* Olsen-Pfitzer	IGRF @ date/1962 *Ext:* Olsen-Pfitzer	IGRF @ date/1970 *Ext:* Olsen-Pfitzer
w/ SAA Translation	Rotated 0.3°/year from 1962 to run year	Rotated 0.3°/year from 1962 to run year	Rotated 0.3°/year from 1962 to run year	Rotated 0.3°/year from 1970 to run year
	AE9		**AP9**	
CmdLine Ae9Ap9	IGRF @ appropriate date *Ext:* Olsen-Pfitzer		IGRF @ appropriate date *Ext:* Olsen-Pfitzer	
References: Jensen and Cain [1962]; GSFC 12/66, updated to 1970 [Cain et al., 1967]; IGRF (no extrapolation of field beyond 01 Jan 2015) [IAGA, 2010]; Olsen-Pfitzer [1977]				

- The interpolation methods applied to the AE8/AP8 flux maps are different. For interpolation in spatial location, the implementation within CmdLineAe9Ap9 uses the original NASA-published algorithm, whereas the SPENVIS uses an improved version for smoother maps [*Heynderickx et al.*, 1996]. This can result in differences between the profiles of flux vs. time or location between the implementations, with the CmdLineAe9Ap9 implementation results being less smooth (however, overall fluxes are still comparable). In addition, the original AE8/AP8 models provided only integral flux values. Their subsequent conversion to differential flux may be implementation-specific as well.
- The application defaults of the respective AE8/AP8 model implementations are different, so proper comparisons will require adjustment to these settings. In CmdLineAe9Ap9, the 'Advanced' magnetic field option 'SAA Translations' should be set to ON to more closely match the magnetic field model used in SPENVIS and IRBEM, and therefore produce a better match of the flux values.
- The SPENVIS AE8/AP8 model implementation uses fixed sets of 30 energy levels for electrons and protons, while the CmdLineAe9Ap9 implementation uses fixed sets of 21 energy levels each. Some of the differences observed in the differential flux results may be partly due to the relative spacing of the energy levels within their respective sets.
- The form of the input ephemeris time values is different between these three applications. IRBEM routines require a year, day of year, and seconds of day. The CmdLineAe9Ap9 application uses Modified Julian Date for input (and output) of time values. SPENVIS is also documented to use "Modified Julian Date", but uses a different definition for this value (see *Alerts to Users* below).

5. Recent Modifications of the CmdLineAe9Ap9 and IRBEM Implementations

- CmdlineAe9Ap9: The routines for AE8 and AP8 models have been revised to calculate the differential flux values from the integral flux values using a power-law method, instead of a linear method. This correction is implemented in AE9/AP9/SPM V1.1.

- CmdlineAe9Ap9: The SHIELDOSE2 model database containing the Bremsstrahlung data tables has been updated to correct the error present in the original SHIELDOSE2 publication. The error is in the 'elbrbas2.dat' file: except for Al detector targets, the finite and semi-infinite slab data tables for Bremsstrahlung have been reversed [*Heynderickx*, private communication, May 2013]. This correction is implemented in AE9/AP9/SPM V1.1.
- IRBEM library: The routine used for the (internal) loading of the Bremsstrahlung data tables has been modified to correct the error present in the original SHIELDOSE2 publication [*Heynderickx,* private communication, May 2013]. This correction is implemented in IRBEM library as of July 2013.

6. Alerts to SPENVIS Users

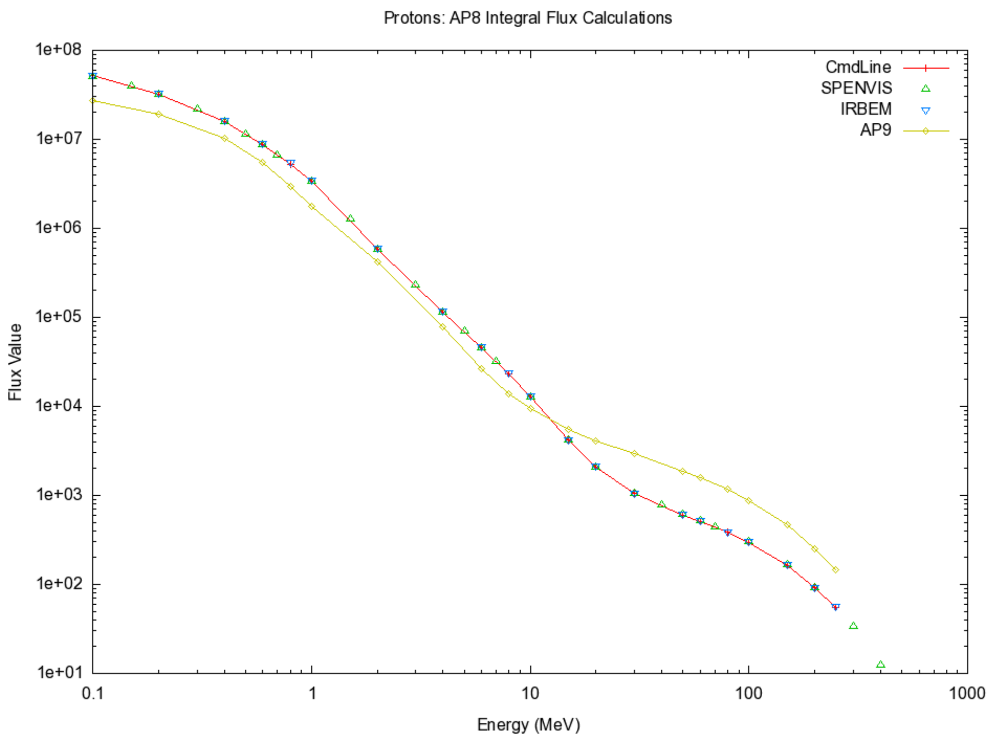
- SPENVIS uses a non-standard definition of Modified Julian Date (MJD) for date input. MJD is normally defined as JD-2400000.5, such that 0000 GMT on 17 Nov 1858 is MJD=0. In SPENVIS, MJD is defined (for input) as time from 0000 GMT on 01 Jan 1950 (see http://www.spenvis.oma.be/help/models/sapre.html).
- The implementation of SHIELDOSE2 in the CmdLineAe9Ap9 application and the IRBEM library follows the original SHIELDOSE2 code in that doses for spherical geometries are calculated for fluxes over a *hemisphere*, rather than from a full sphere. Therefore, these dose results should be multiplied by 2 when comparing them to the full-sphere dose results from SPENVIS.

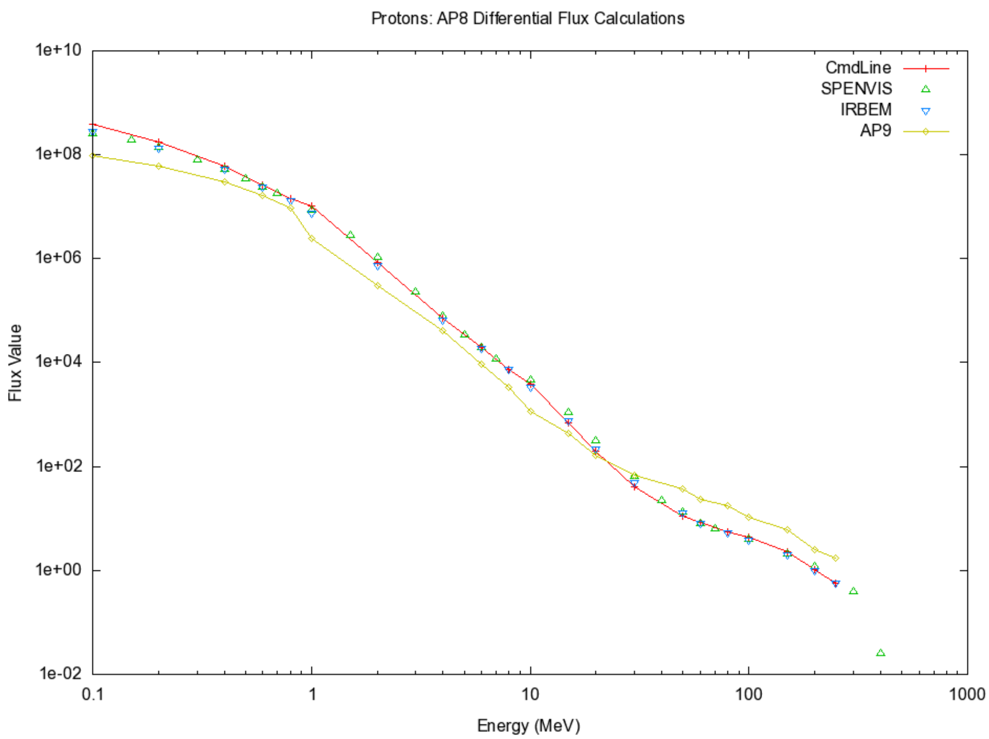
7. Plots

Proton Fluxes:

Integral Fluxes are a near-exact match between the three AP8 model implementations.

Differential Fluxes show some minor differences, attributable to differences in the magnetic field model and processing settings.

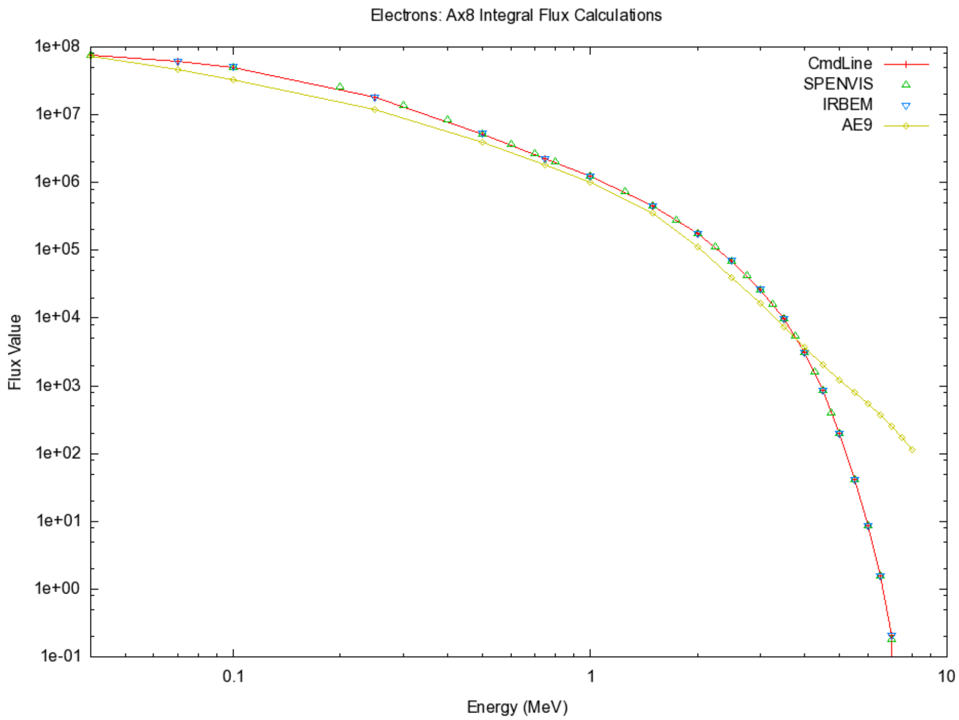


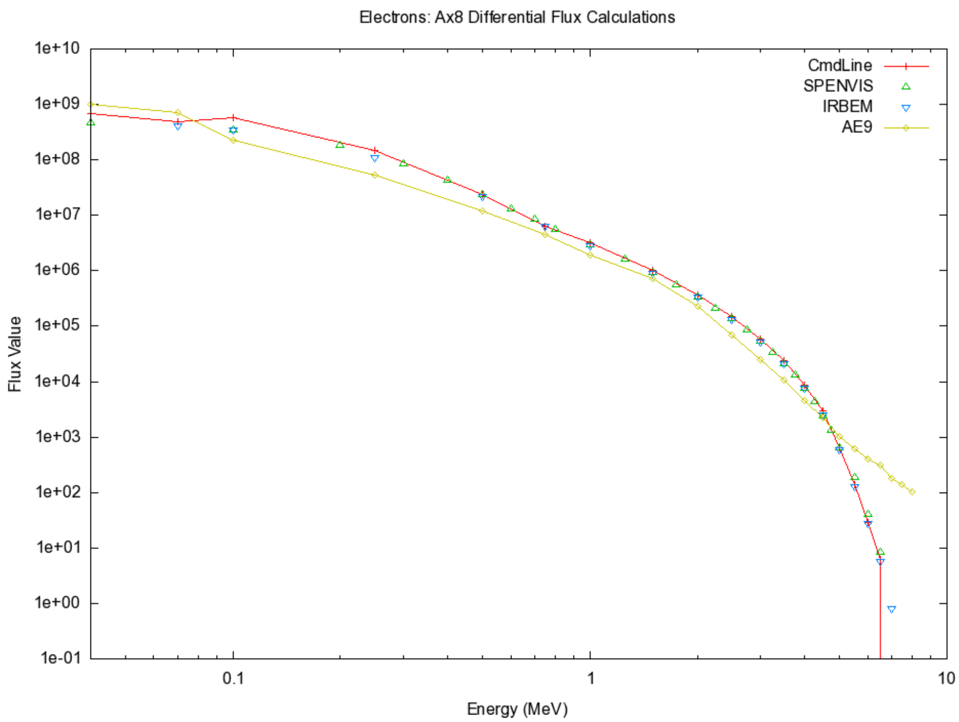


Electron Fluxes:

Integral Fluxes are a near-exact match between the three AE8 model implementations.

Differential Fluxes show some minor differences, attributable to differences in the magnetic field model and processing settings.





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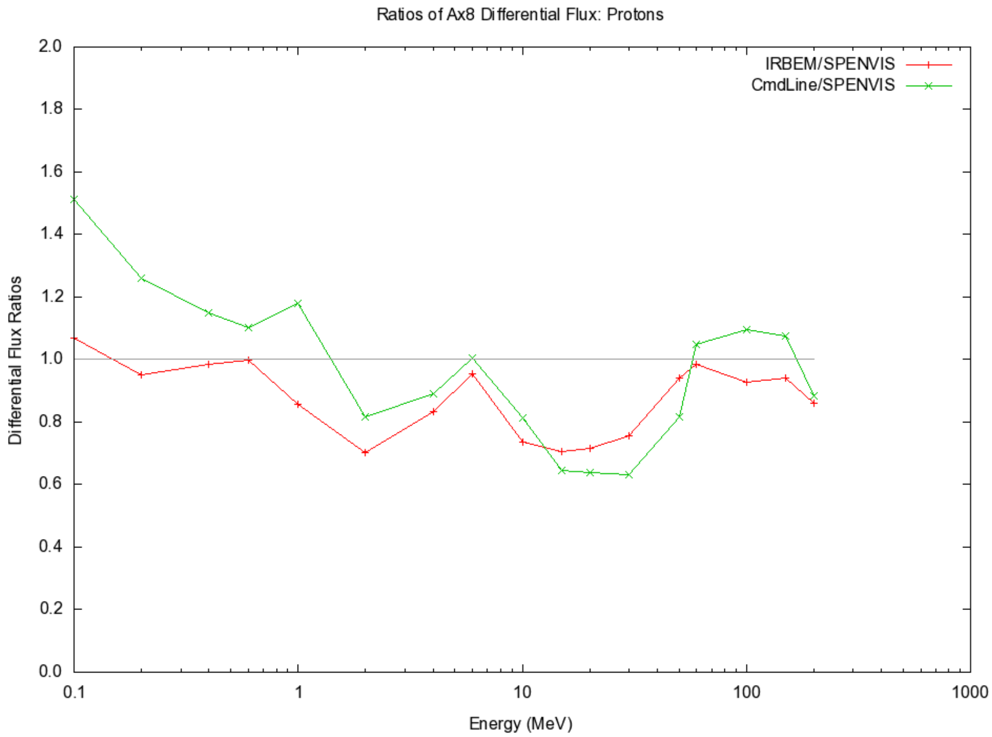
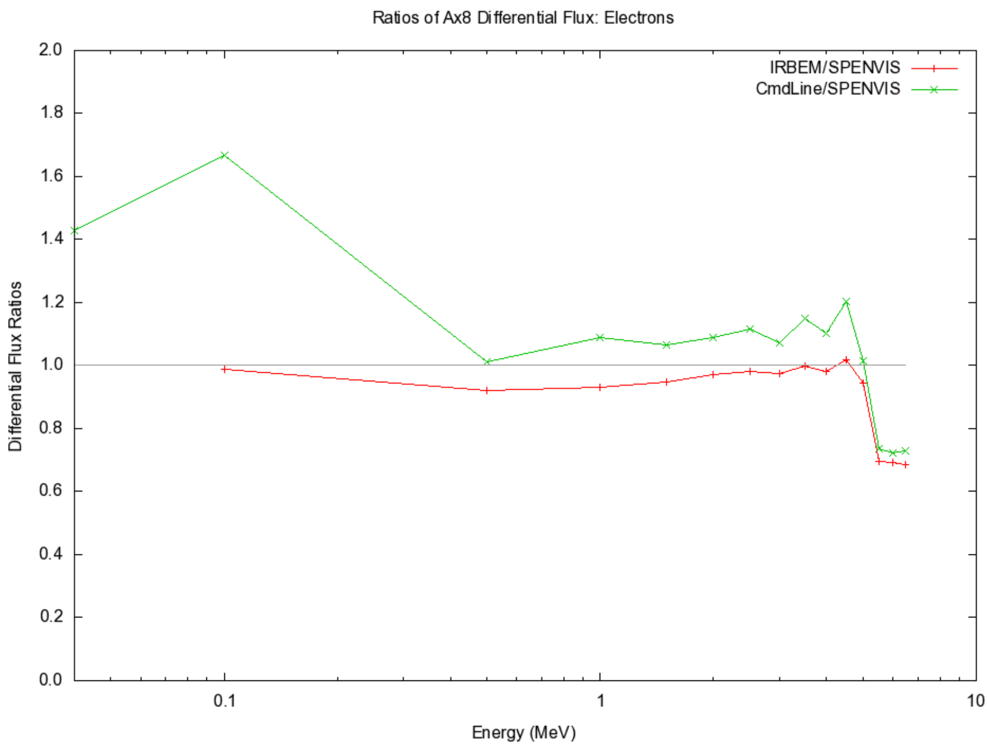
Ratios of Differential Fluxes:

Differential fluxes, used as input for the dose calculations, show some minor differences relative to SPENVIS, attributable to differences in the magnetic field model and processing settings.

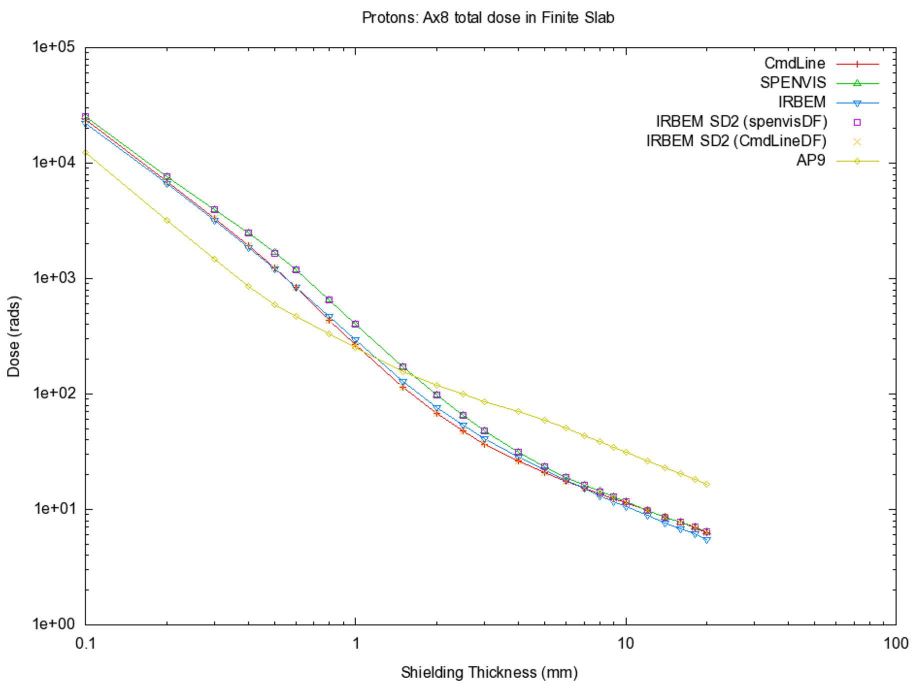


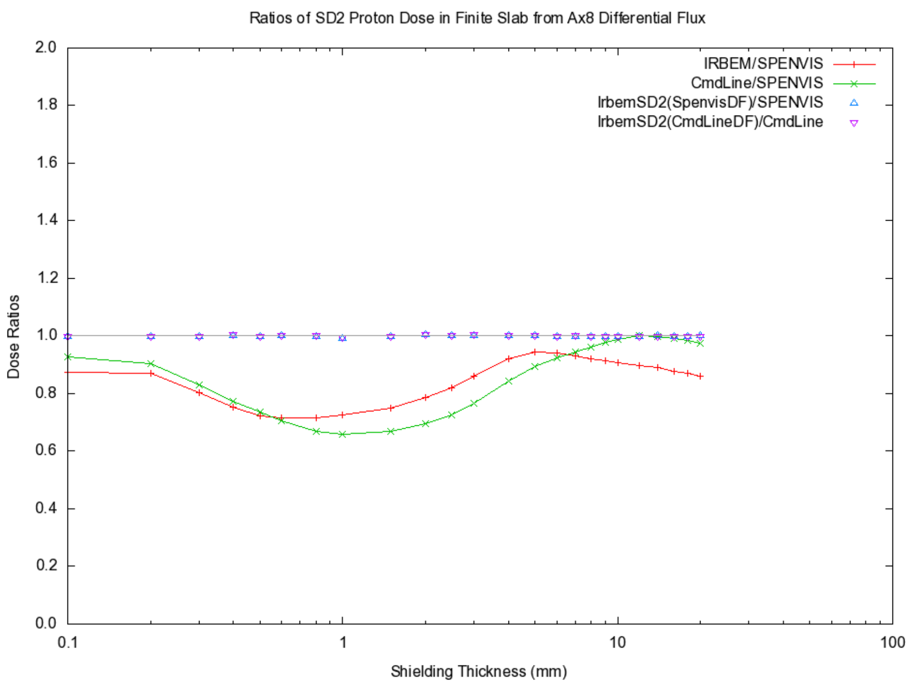


Proton Dose Results: Finite Slab

(for protons, the results for Semi-infinite slab geometry are identical)

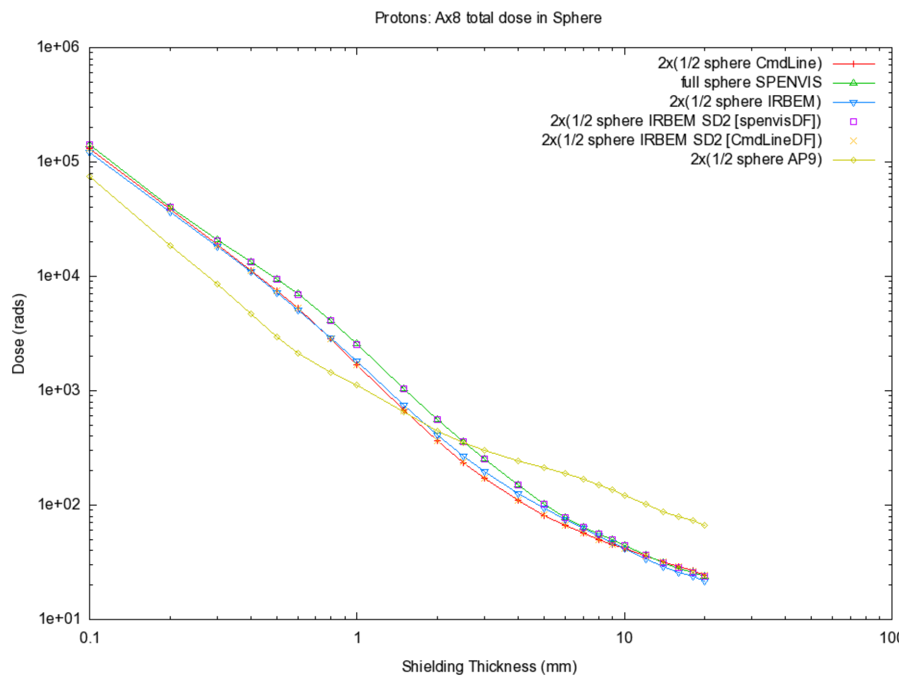
Doses are mostly matching, with some minor differences that are attributable to the small differences in the input differential flux values. Use of the IRBEM implementation of SHIELDOSE2 with the CmdlineAe9Ap9 application and SPENVIS differential flux values reproduce their respective dose results.

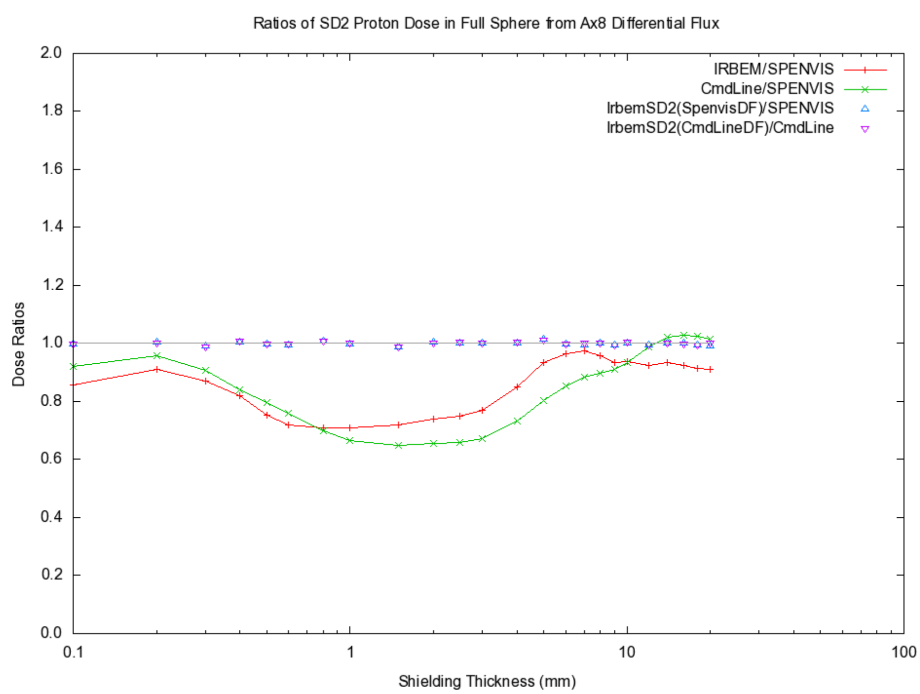




Proton Dose Results: Full Sphere

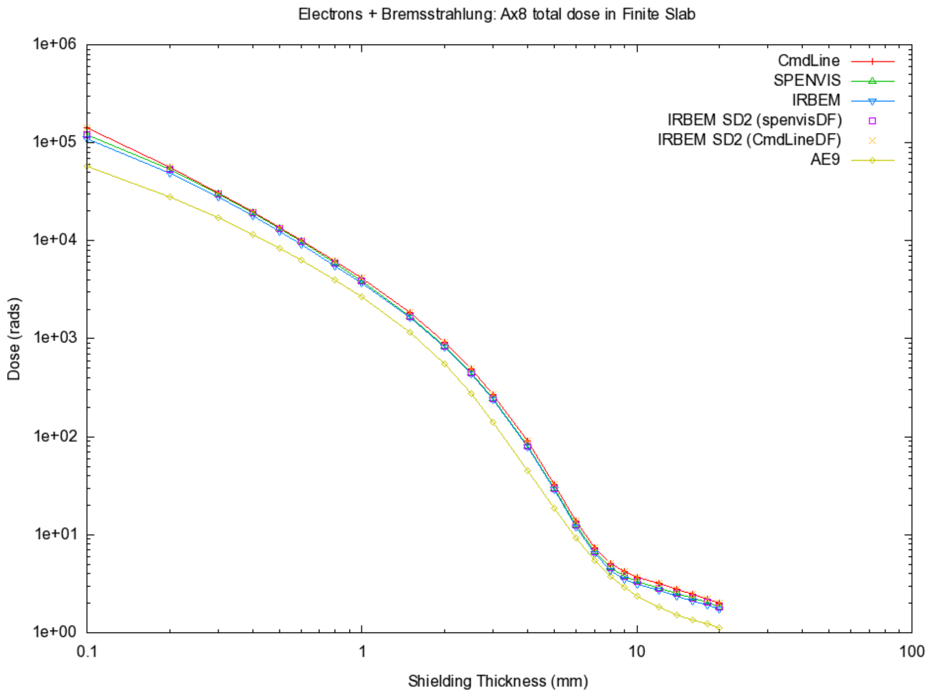
Doses are mostly matching, with some minor differences that are attributable to the small differences in the input differential flux values. Use of the IRBEM implementation of SHIELDOSE2 with the CmdlineAe9Ap9 application and SPENVIS differential flux values reproduce their respective dose results.

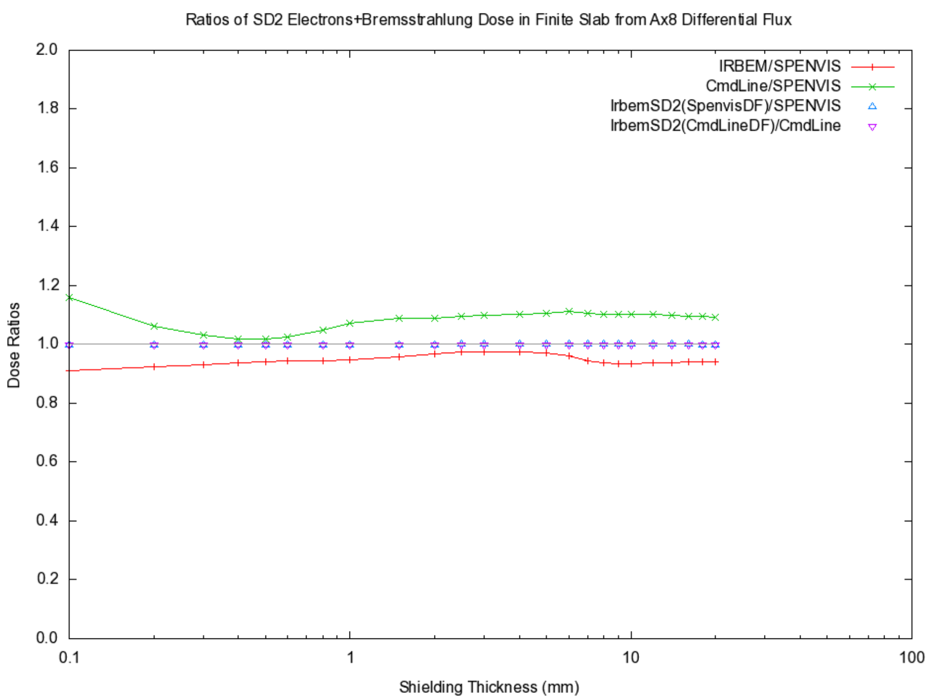




Electron+ Bremsstrahlung Dose Results: Finite Slab

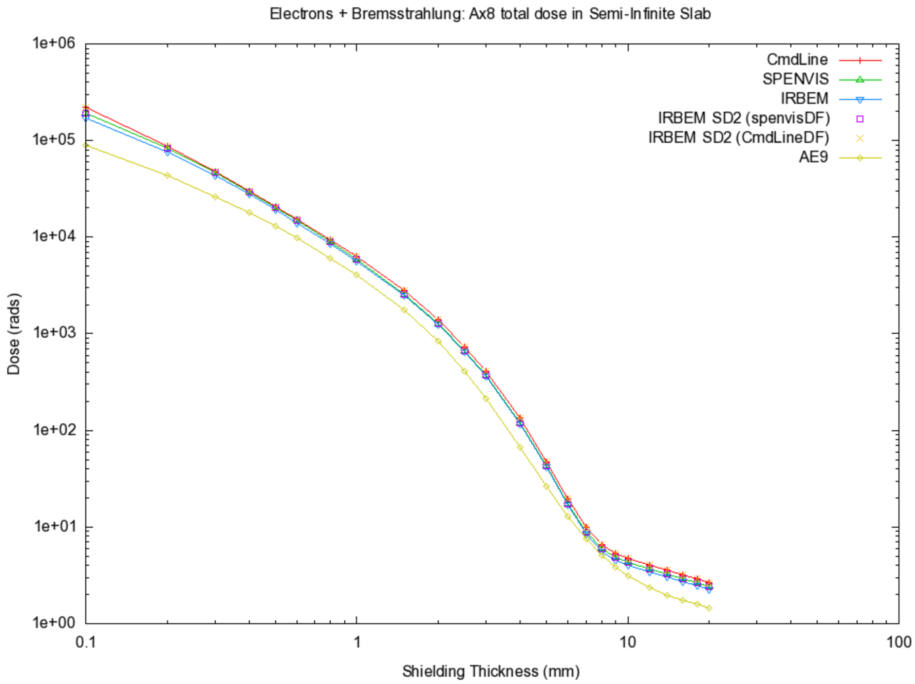
Doses match very closely, with some minor differences that are attributable to the small differences in the input differential flux values. Use of the IRBEM implementation of SHIELDOSE2 with the CmdlineAe9Ap9 application and SPENVIS differential flux values reproduce their respective dose results.

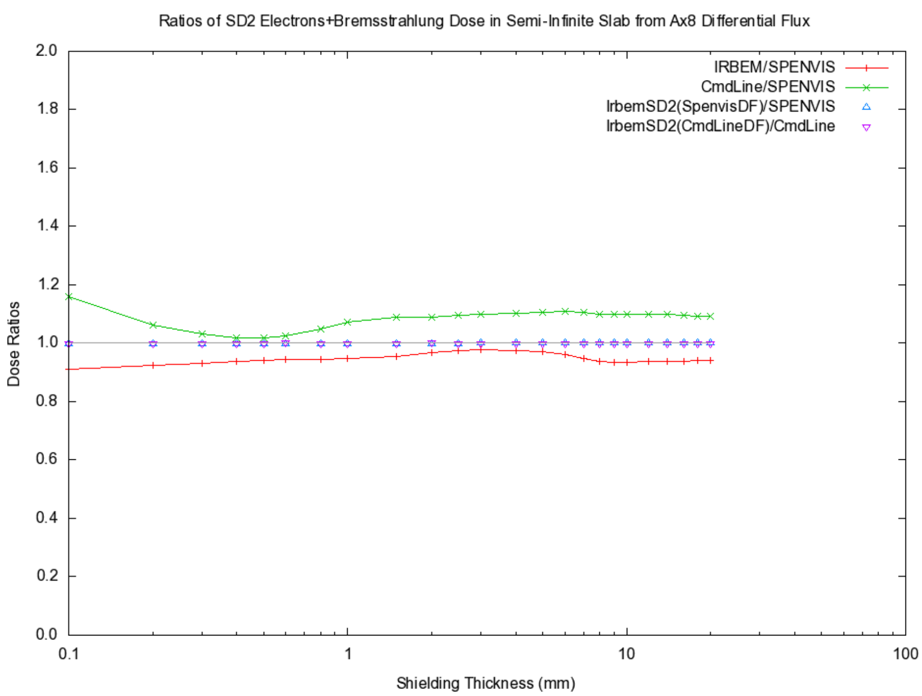




Electron+ Bremsstrahlung Dose Results: Semi-Infinite Slab

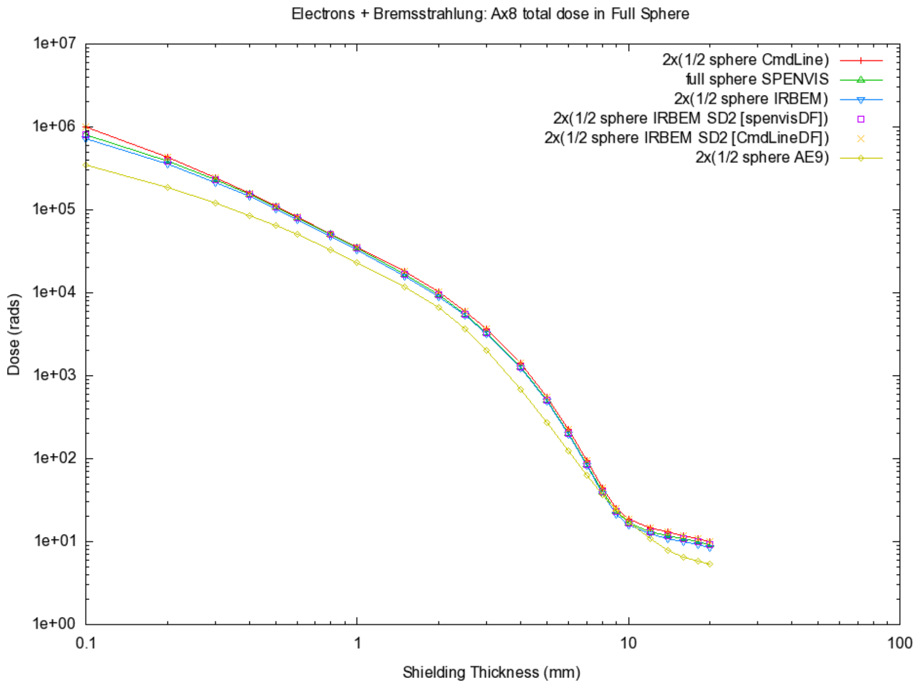
Doses match very closely, with some minor differences that are attributable to the small differences in the input differential flux values. Use of the IRBEM implementation of SHIELDOSE2 with the CmdlineAe9Ap9 application and SPENVIS differential flux values reproduce their respective dose results.

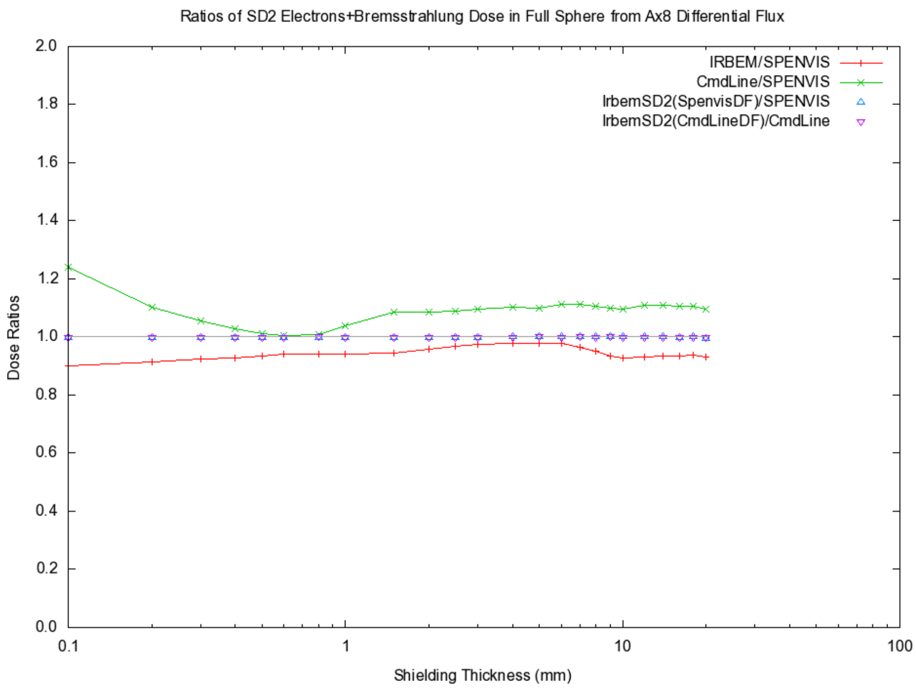




Electron+ Bremsstrahlung Dose Results: Full Sphere

Doses match very closely, with some minor differences that are attributable to the small differences in the input differential flux values. Use of the IRBEM implementation of SHIELDOSE2 with the CmdlineAe9Ap9 application and SPENVIS differential flux values reproduce their respective dose results.





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