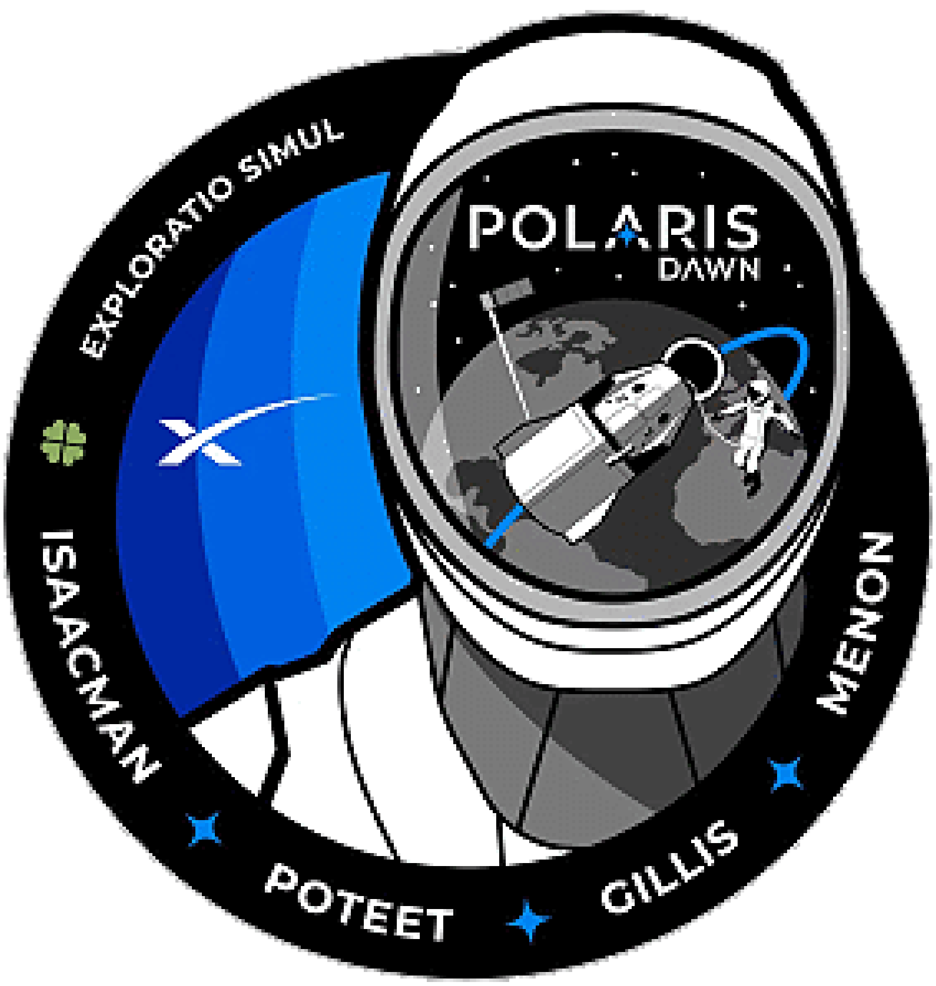
Exercise 3a: Calculate the total dose an astronaut would have received during the private human spaceflight mission Polaris Dawn

Mission overview

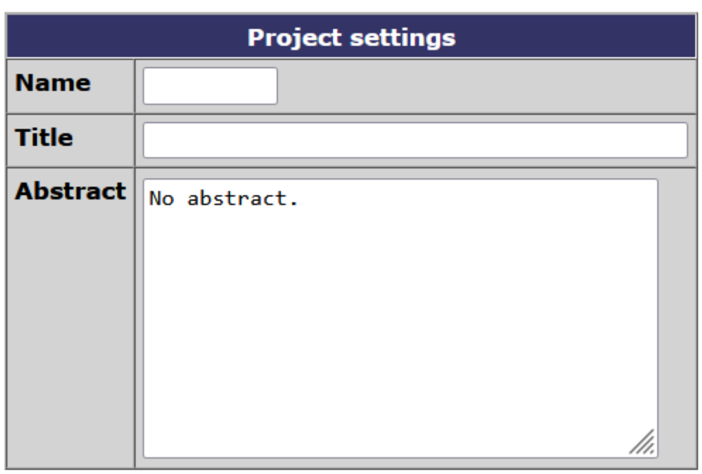
Spacecraft	SpaceX Crew Dragon Resilience SATCAT 61042 (COSPAR ID 2024-161A)
Crew	Jared Isaacman, Scott Poteet, Sarah Gillis, Anna Menon
Launch	September 10, 2024, 09:24 UTC, Kennedy Space Center (US)
Landing	September 15, 2024, 07:37 UTC, Gulf of Mexico, near Dry Tortugas, Florida (US)
Trajectory	Low Earth Orbit (51.7°), period ~106 minutes



STEP 0 - Access SPENVIS and create a project

Go to **https:/www.spenvis.oma.be** and click on **SIGN IN** button to access the SPENVIS system. We will provide you with a username and password.

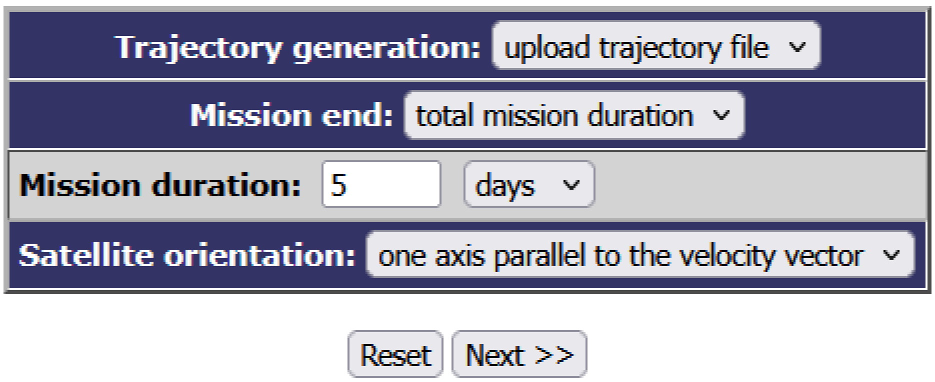
Once you have logged in, the first step is to create a project. You can enter e.g. twice Polaris_Dawn for the **Name** and **Title**. You do need to provide anything for the **Abstract** (optional information).



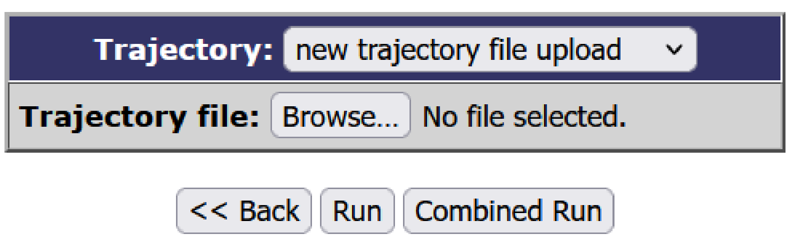
STEP 1 - Define the mission in SPENVIS

First, you need to specify the type of the orbit. Select **Coordinate generators** from the SPENVIS **Model packages** page and click on **Spacecraft trajectories**. Then, select the "**upload trajectory file**" option for the **Trajectory generation**.

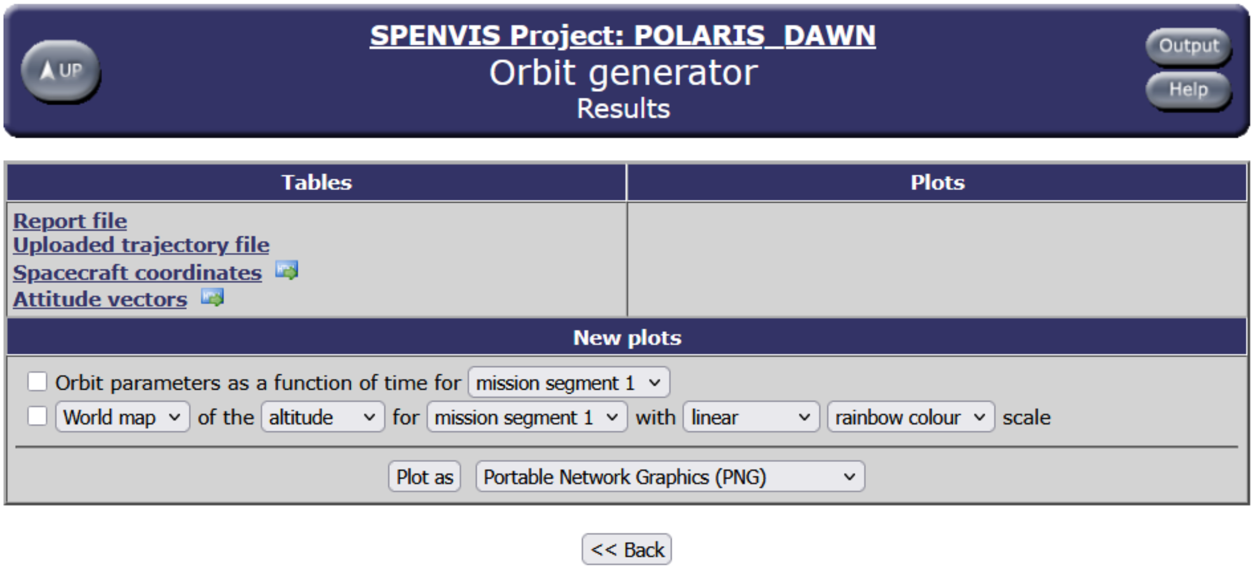
Set the **Mission duration** equal to 5.0 days. Then click **Next**.



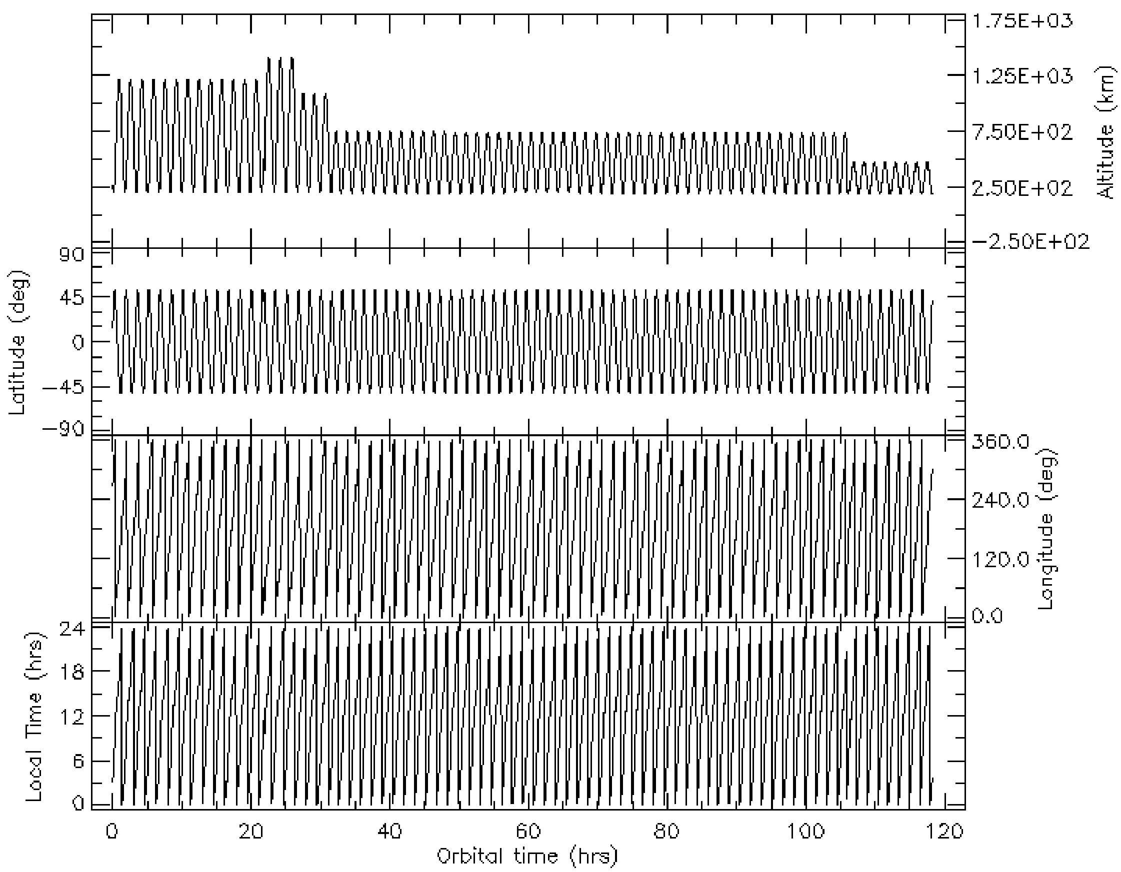
Select the "**new trajectory file upload**" option. Then click on the **Browse** button to upload the file containing the Polaris Dawn trajectory (Polaris_dawn.trj).



Then click **Run**. The program will now generate the mission orbit with your preferences and you will see the following page:



Tick the box next to **Orbit parameters as a function of time** and click on the **Plot as** button. A file will be added under **Plots**. You can click on it to view it.



Further investigation (optional)

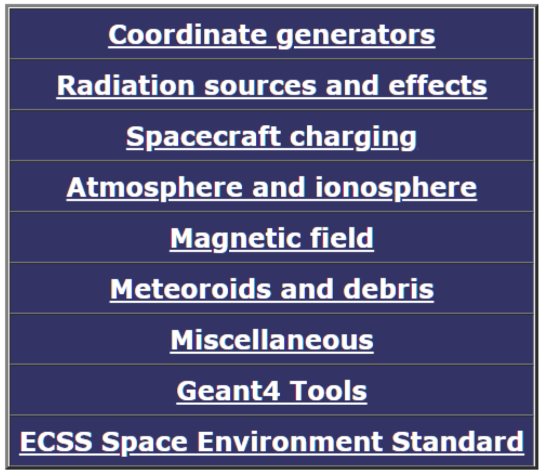
1. Looking at the **Orbit parameters as a function of time** plot can you tell if there was a change in the trajectory of the spacecraft (for example a spacecraft manoeuvre using thrusters)? Hint: Look for a sudden change in the altitude of the spacecraft..

2. You can also tick the second box under **New plots** and click on the first tap to select the **World map** option (the default option is **Time plot**) to generate a plot of the trajectory as it is projected on a world map.

If you look at the world map plot, what part of the globe is covered by the mission? Can you think of what can affect the latitude coverage?

STEP 2 – Environment definition

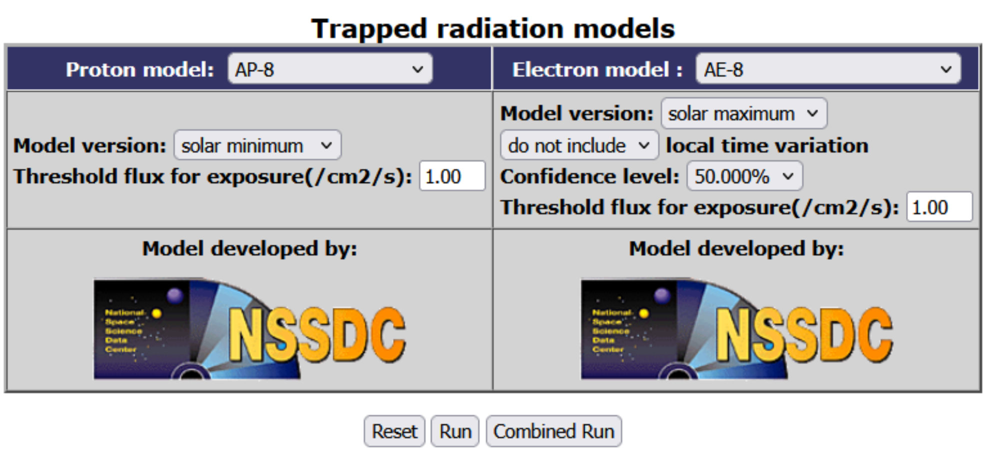
We will now define the environment, meaning we will let the model calculate the expected fluxes of high energy particles on our orbit. Click the **Up** button (upper left corner), to go back to the main menu (**Model packages** page), and choose **Radiation sources and effects**:



For this part you will consider only magnetically trapped particles (protons & electrons) forming the Van Allen Radiation Belts.

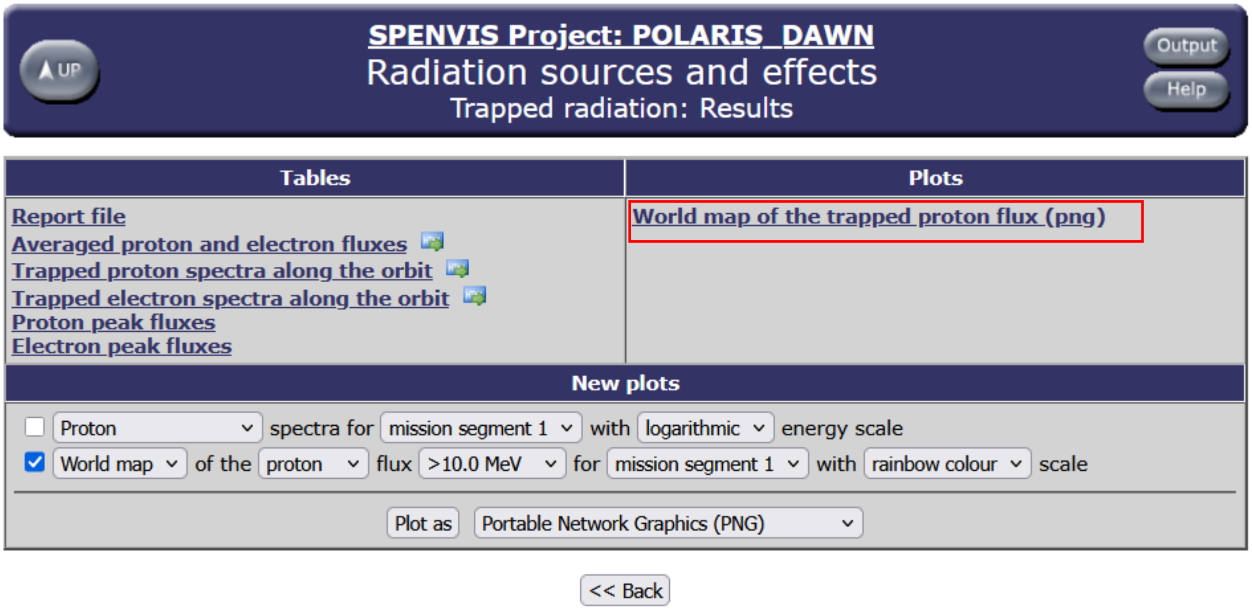
Select **Trapped proton and electron fluxes, Standard models** from the menu. Use the default settings:

- AP-8 solar minimum for trapped proton model
- AE-8 solar maximum for trapped electron model

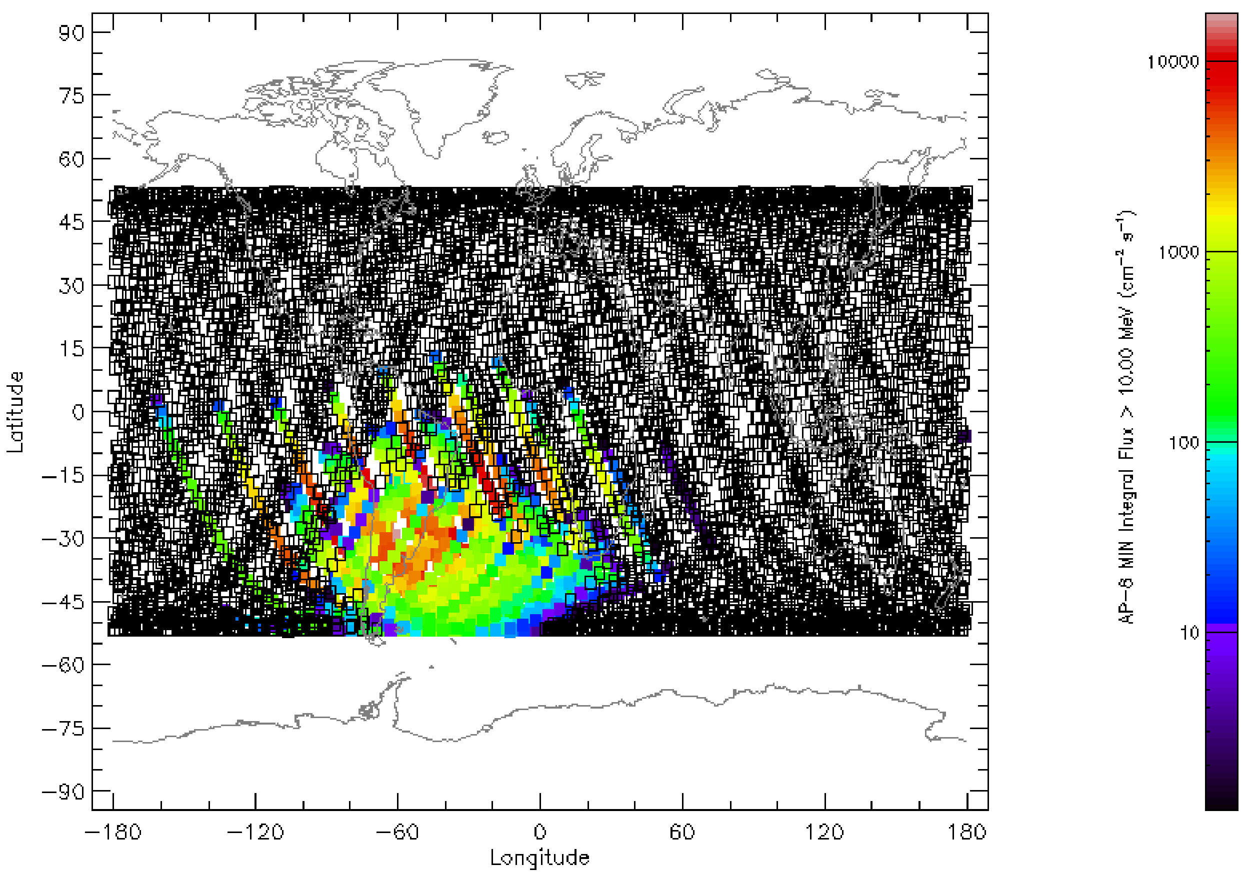


Click **Run** to calculate the trapped particle fluxes. You will then see the **Trapped radiation: Results** page. Tick the **second box** under **New plots** and click on the first tap to select the **World map** option (the default option is **Time plot**) and choose **> 10.0 MeV** for the proton energy.

Click on the **Plot as** button to generate the plot for **proton**.



The file will appear under **Plot** and you can click on it to view it. This plot gives you an idea of the spacecraft orbit around Earth and the encountered radiation environment due to the magnetically trapped protons.



You will notice that the particle fluxes are higher in the region above South America and up to the south west coast of Africa. Can you think a reason for that? **Hint:** This phenomenon is called the **South Atlantic Anomaly (SAA)**

Further investigation (optional)

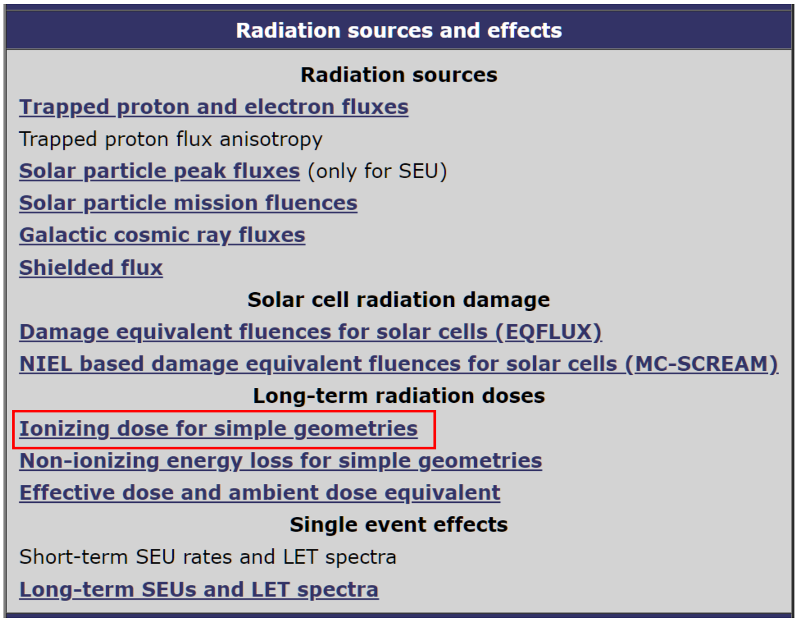
1. Look how the plot changes if you select different proton energies.

2. In a similar way, you can generate the plots for electron. What could explain the differences between electrons and protons?

To continue, click again the **UP** button at the upper left.

STEP 3 - Total Ionising Dose (TID) calculation

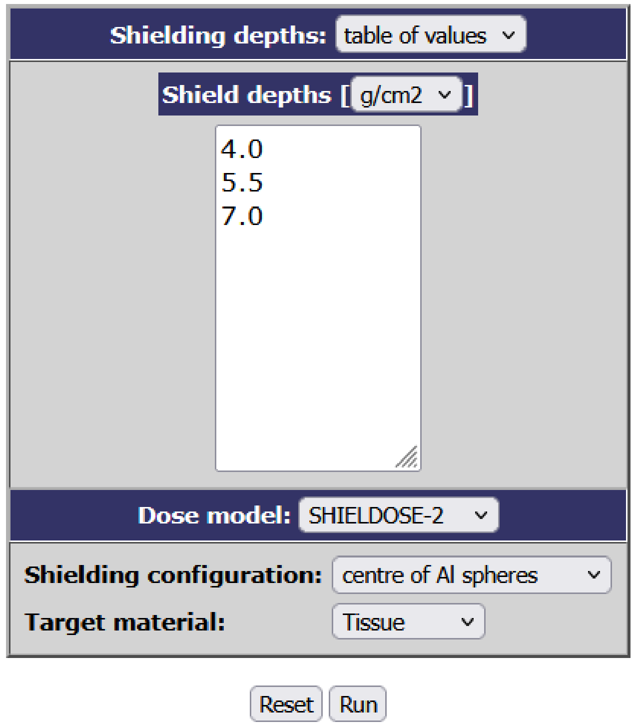
For this final step you need to select the model for calculating the radiation doses. Back in the main menu, you will see that most of the options are now 'clickable'. Choose **Ionizing dose for simple geometries** (under the subtitle **Long term radiation doses**):



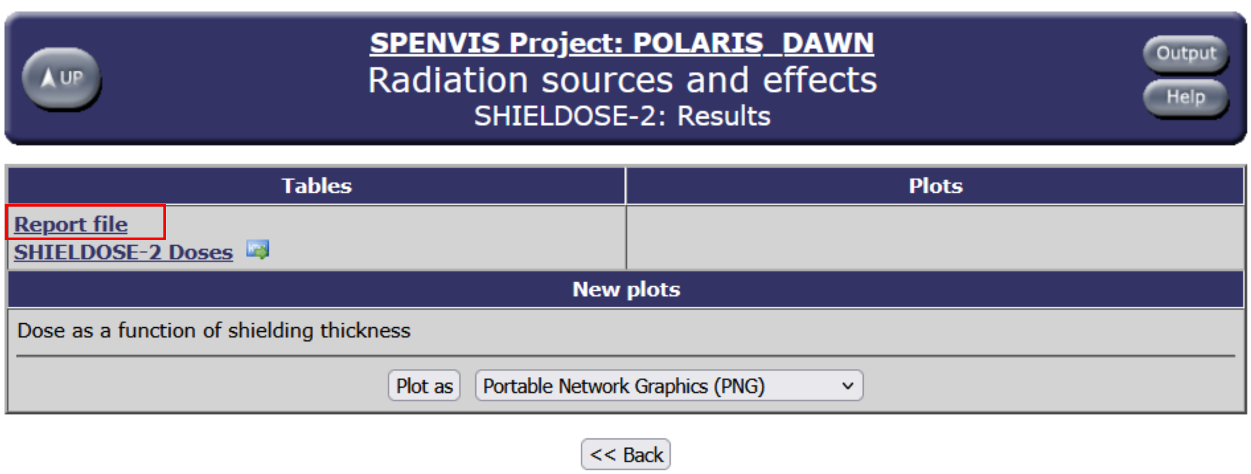
To keep it simple, we assume that the spacecraft is a simple solid sphere around the target where the dose will be calculated. For **Shielding depths** select **table of values**, which will allow you to define your own choice of radiation shield.

You need to provide the following input:

- Shield depths of **4.0, 5.5** and **7.0** in units of **g/cm2** (put these numbers under each other in the white field),
- Dose model: keep the default "SHIELDOSE-2",
- Shielding configuration: **centre of Al spheres**,
- Target material: **Tissue** (to look at the radiation effects on humans).



Click on the **Run** button to generate your results. Once the run is completed the following page will appear:



Click on the **Report file** option to open calculation report. Look up the total mission dose in rad (under **Total**) for Al absorber thickness values equal to 4.0, 5.5 and 7.0 g/cm2. Fill the total doses in rad and Al absorber thickness values in mm in **Table 1** below.

You have calculated the amount of energy deposited per unit mass in the tissue of an astronaut behind the three spacecraft thicknesses in units of rad. Note that the SI units for absorbed dose is Gy (gray).

Next, you need to calculate the absorbed dose in units of mGy (milli gray) that is more useful for comparison (using the fact that 1 rad is equal to 10 mGy):

*Absorbed dose (mGy) = Absorbed dose (rad) * 0.1*

There are other quantities that are more meaningful when considering the biological effects of radiation such as the equivalent dose. However, these calculations require a radiation weighting factor (dimensionless) that depends on the radiation type and energy.

You can make a rough estimation of the dose equivalent for your mission assuming a weighting factor equal to 2.0 and use the following formula to calculate the experienced dose equivalent in units of mSv (milli sievert):

*Dose equivalent (mSv) = weighting factor * Absorbed dose (mGy)*

Register your results in the table below.

Table 1 Absorbed dose and dose equivalent during 5.0 days mission and one year exposure

Al thickness		**5.0 days mission**			**1 year exposure**		
		Absorbed dose		Dose equiv.	Absorbed dose		Dose equiv.
g/cm2	mm	rad	mGy	mSv	rad	mGy	mSv
4.0							
5.5							
7.0							

Do you think that the radiation exposure during the mission is acceptable? Note that the a dental x-ray delivers 0.005 mSv on an adult person and a transatlantic flight 0.08 mSv.

There is an average exposure to ionising radiation here on Earth that includes natural sources and medical applications. For example, in Belgium it was 4 mSv for the year 2015.

Further investigation (optional)

1. Dose can be accumulated meaning that longer exposures can result to higher absorbed doses for the spacecraft crew.

For simplicity, you can make the assumption that the space radiation environment encountered by the spacecraft does not change during the period of one year. Then, you can use the rule of three to calculate the doses for a yearly exposure on the same spacecraft trajectory.

*Absorbed dose (year) = (Absorbed dose (mission) * 365) / 5.0*

*Dose equivalent (year) = (Dose equivalent (mission) * 365) / 5.0*

Register your results in the **Table 1** above.

2. The International Commission on Radiological Protection (ICRP) recommends a yearly limit on the **effective dose** (weighted sum of all equivalent doses in specified tissues and organs of the human body) equal to 1 mSv for the public and 50 mSv for occupationally exposed workers.

Note that these limits are for additional contribution above the normal exposure level from common sources. As we mentioned before, the **average exposure** to ionising radiation in Belgium was 4 mSv for the year 2015.

How do these values compare with your results?

3. The above assumption that the space radiation environment does not change during a long period is not actually correct… Can you think of why (see also Exercise 1b)?

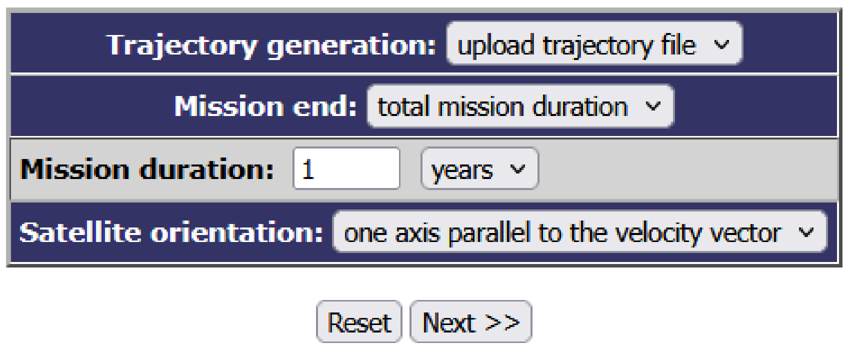
Exercise 3b: Calculate the total dose an astronaut would have received during one year mission for the same orbit as Polaris Dawn

You should try this after you have completed Exercise 3a. You can still use the same project as before.

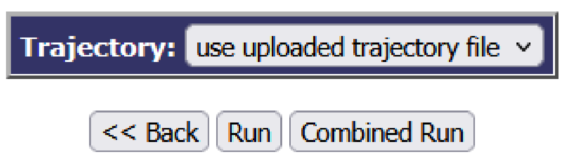
STEP 1 - Define the mission in SPENVIS

First, you need to specify the type of the orbit. Select **Coordinate generators** from the SPENVIS **Model packages** page. Select the "**upload trajectory file**" option for the **Trajectory generation**.

Set the **Mission duration** equal to 1 year. Then click **Next**.



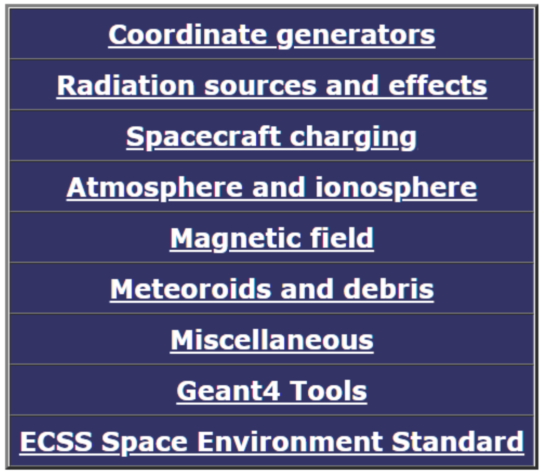
Since you have already uploaded a trajectory file you can select the "**use uploaded trajectory file**" option and hit the **Run** button.



Note that SPENVIS will delete your previous results (for example particle fluxes and doses) every time you run the Coordinate generator.

STEP 2 – Environment definition

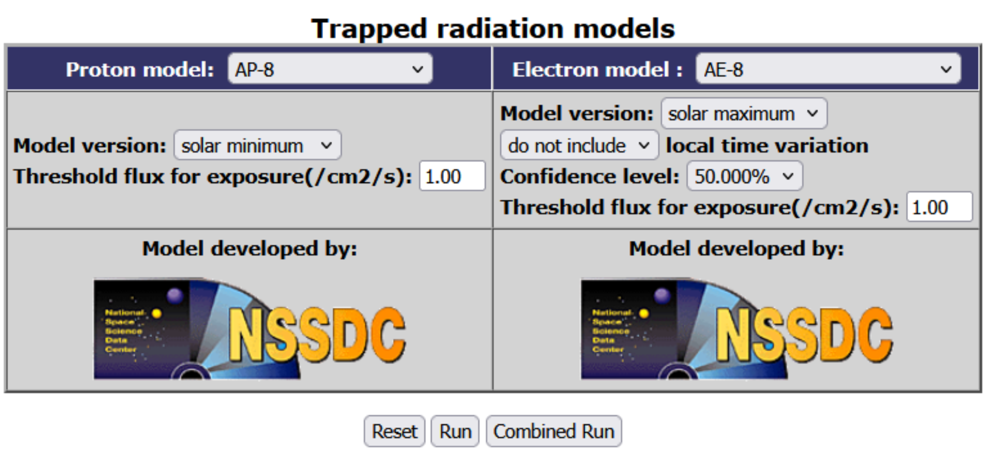
We will now define the environment, meaning we will let the model calculate the expected fluxes of high energy particles on our orbit. Click the **Up** button (upper left corner), to go back to the main menu (**Model packages** page), and choose **Radiation sources and effects**:



For this part you will consider the magnetically trapped particles (protons & electrons) but also solar energetic protons.

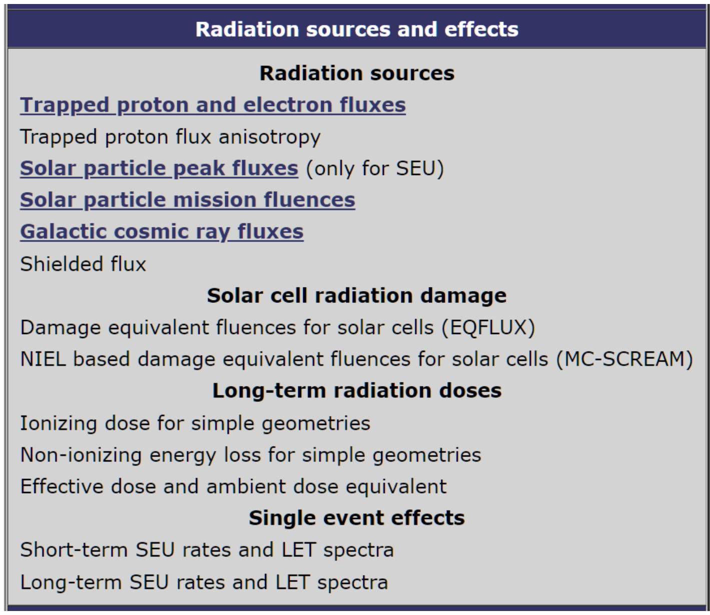
First, select **Trapped proton and electron fluxes, Standard models** from the menu. Use again the default settings:

- AP-8 solar minimum for trapped proton model
- AE-8 solar maximum for trapped electron model

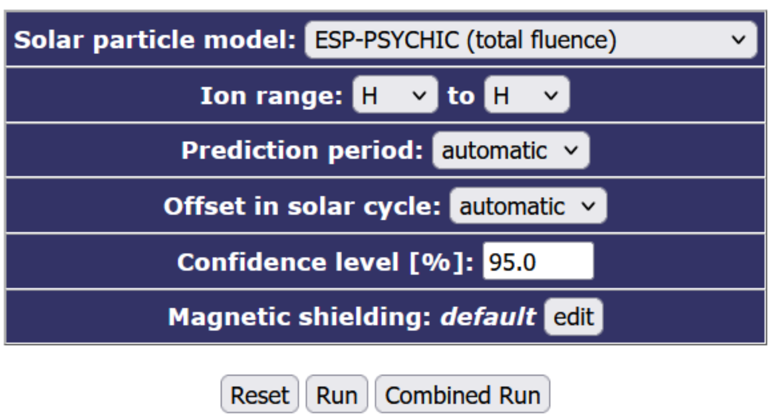


Click **Run** to calculate the trapped particle fluxes. You will then see the **Trapped radiation: Results** page. You do not need to consult the results but you can generate **World map** plots (similar to Exercise 3a) if you want.

To continue, click again the **UP** button at the upper left and select **Solar particle mission fluences** from the menu.



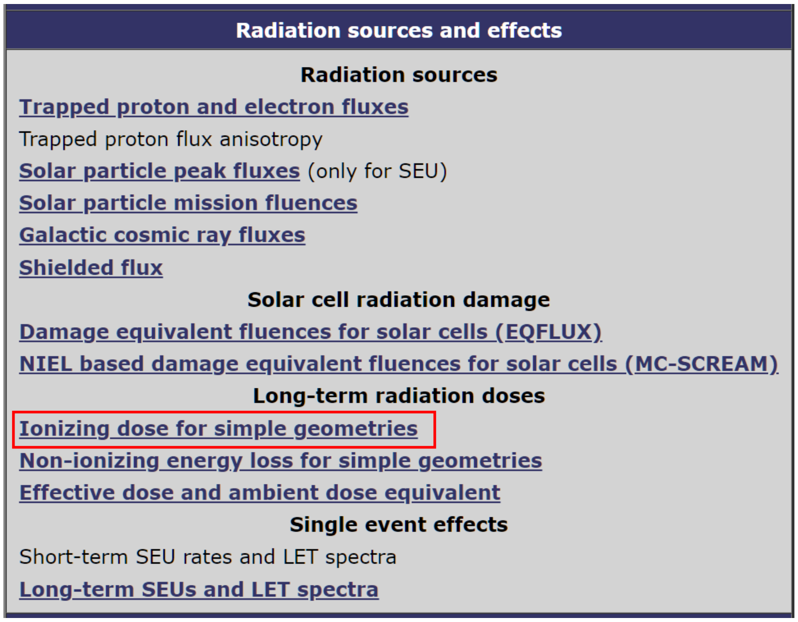
Note that these are statistical models providing information about solar particle events over mission durations of one year or more. For this exercise we need only the solar proton radiation environment so you can limit the **Ion range** from **H** to **H**.



After that click **Run** to let the model calculate the solar proton fluences. You do not need to consult the results (they will be used automatically for the dose calculation later on). Click the **UP** button again to go back.

STEP 3 - Total Ionising Dose (TID) calculation

For this final step you need to select again the **Ionizing dose for simple geometries** option (under the subtitle **Long term radiation doses**).



You can make the same assumptions as in the previous exercise and select the **table of values** option for **Shielding depths**. You will also need to provide the following input:

- Shield depths of **4.0, 5.5** and **7.0** in units of **g/cm2** (put these numbers under each other in the white field),
- Dose model: keep the default “SHIELDOSE-2”,
- Shielding configuration: **centre of Al spheres**,
- Target material: **Tissue** (to look at the radiation effects on humans).

Click on the **Run** button to generate your results. Once the run is completed click on the **Report file** option to open calculation report. Copy the results in the table below.

You can calculate again the absorbed dose in units of mGy and the dose equivalent in units of mSv (assuming again a weighting factor equal to 2.0):

$$\textit{Absorbed dose (mGy)} = \textit{Absorbed dose (rad)} * 0.1$$

$$\textit{Dose equivalent (mSv)} = \textit{weighting factor} * \textit{Absorbed dose (mGy)}$$

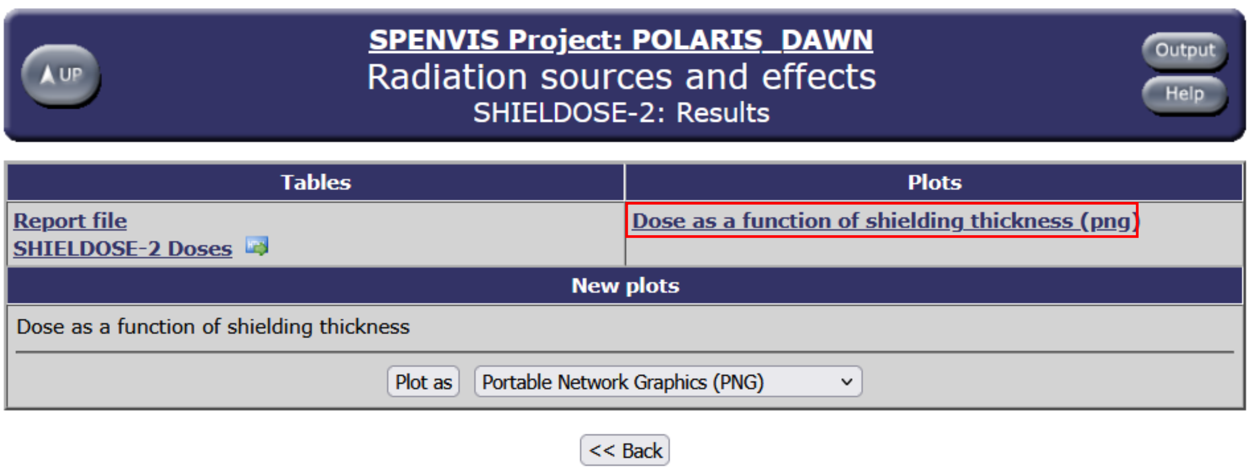
Register your results in **Table 2**.

Table 2 Absorbed dose and dose equivalent during 1 year mission

Al thickness		1 year mission		
		Absorbed dose		Dose equiv.
g/cm2	mm	rad	mGy	mSv
4.0				
5.5				
7.0				

How do those results compare with the ones from Exercise 3a?

You can make a plot of the **Dose as a function of shielding thickness** by clicking on the button.



Click on the generated **Dose as a function of shielding thickness (png)** file to open the plot. Which particles (trapped or solar protons) contribute more to the resulting doses?