Exercise: Cutoffs

23rd FLUKA Beginner's Course
Lanzhou University
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Objectives

Learn how to...

- ... examine the effect of setting different thresholds values
- ... practice the use of preprocessor directives.
- ... strengthen plotting skills
- ... further interact with the FLUKA manual.

Disclaimer

The example provided is intended to be used for educational purposes **only** and not representative of a real scenario.

Exercise: Cutoffs and thresholds (part 1)

Copy the input file from the `transport_v1.inp` in a newly created directory and change its name:

```
mkdir new_cut
cd new_cut
cp ../Exercises/Transport_exercise/transport_v1.inp .
mv transport_v1.inp yourtransport_v1.inp
```

Open the input with *flair*:

```
flair yourtransport_v1.inp &
```

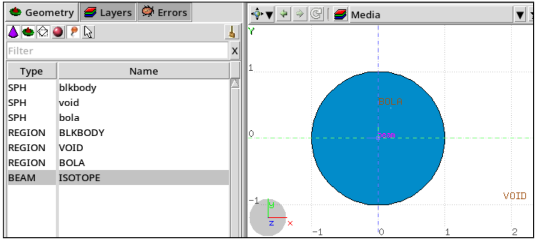
Save the flair project as `yourtransport_v1.flair` ("flair" tab and then click "save project as")

Exercise: Cutoffs and thresholds (part 1)

The input consists of a source of ^{18}F[1], which is a positron emitter ($\sim$ 635 keV), inspect the geometry…it is indeed empty!

- Place a sphere body centered at the origin, with 1 cm radius.
- Create a unique region for that sphere and assign "WATER" to it.

  It should look like this:



[1] note the ISOTOPE beam

Exercise: Cutoffs and thresholds (part 1)

We will start by defining three different transport thresholds for this problem using EMFCUT, applying the following kinetic energy transport threshold to electrons and positrons:

High-T - 600 keV

Inter-T - 500 keV

Low-T - 100 keV

Specify with WHAT(4) and WHAT(5) the region range the threshold should be applied to, which should include your water sphere.

Suggestion

To apply the thresholds to all regions you can select the first region and then @LASTREG. The same principle applies to materials albeit with a @LASTMAT

Exercise: Cutoffs and thresholds (part 1)

To assess the effect of the threshold cards, we will use estimators to check the spatial distribution of the radiation emanating from the source. We can do this with the built-in scoring estimators, like a USRBIN[2]. Your input scores:

- POSITRON;
- ANNIHRST - annihilation events at rest (note that this is a point quantity)
- PHOTON;

Scoring takes place in a 4 cm $\times$ 4 cm $\times$ 4 cm cube centered at (0,0,0), with binning 0.2 mm

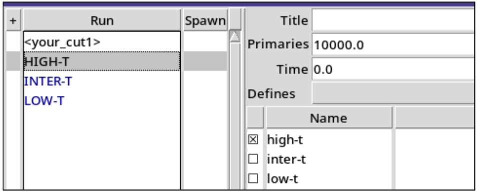
Suggestion

Do not hesitate to consult the manual or the scoring lecture/exercise to refresh your memory

[2] DCYSCORE card: wait for the Activation lecture

Exercise: Cutoffs and thresholds (part 1)

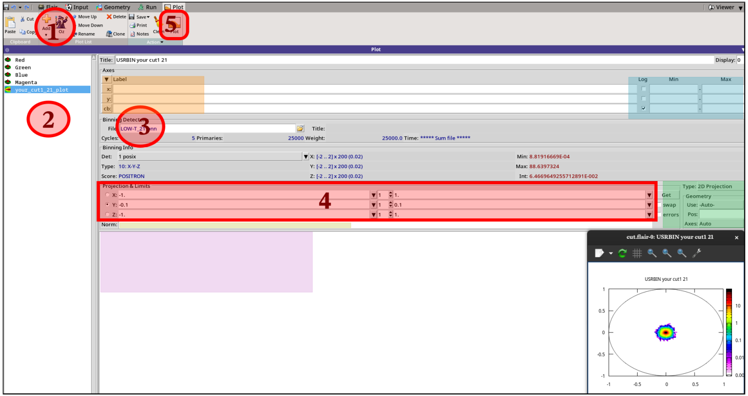
For this type of situations, it is often convenient to use preprocessor directives. You can use them to set up three variables for each of the thresholds aforementioned. Use `#define` to set the variables and `#if`, `#elseif`, `#endif` to each EMFCUT card. In the flair run tab these should appear as:



Run 5 cycles of 10000 primaries for each of the variables (with the others unselected). Do not overwrite the results, name your runs wisely!

Exercise: Cutoffs and thresholds (part 1)

Add a plot (+) or use the "wizard" to generate a unique entry Let us plot the results, in flair go to the Plot tab and follow the 1-5 red sequence below:



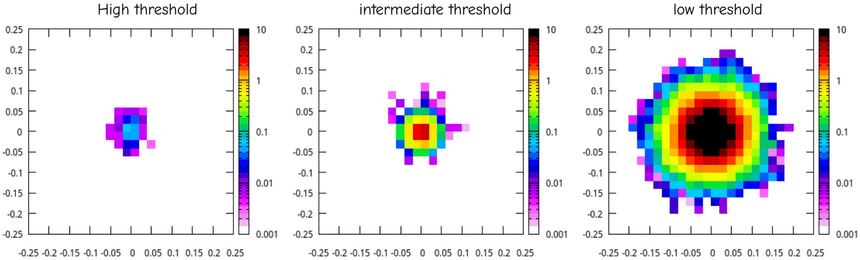
Exercise: Cutoffs and thresholds (part 1)

1. Add a plot (+) or use the “wizard” to generate a unique entry
2. select the created entry, it is a good idea to rename it
3. browse the *.bnn file with the data that you want to plot
4. in the projection use [-1:1] for x and z, select y and use [-0.1:0.1] there
5. click "plot", it should generate a figure and a *.dat file with the plotted data

Suggestion

You might want to explore other useful options, particularly those highlighted such as ’normalization’, ’labels’, ’view options’, ’projection options’ and, if you are familiar with gnuplot, you can use the ’command area’. Explore all buttons you want and see what they do...

Plot the positron *.bnn files of each run. You can zoom in the plot (right click and select an area) and obtain something like:



Explanation

The ^{18}F positrons have a max. range in water of $\sim$ 2.3 mm but they interact easily along the path, losing energy. Once they lose energy below the threshold they are no longer transported.

Exercise: Cutoffs and thresholds (part 1)

You probably noticed that the three runs took a sligthly different time to reach completion. In the output files search for "CPU". Depending on your machine, the time required to “follow” all primary particles will vary but the proportions will be consistent with:

High-T $\sim$ 0.035 s

Inter-T $\sim$ 0.041 s

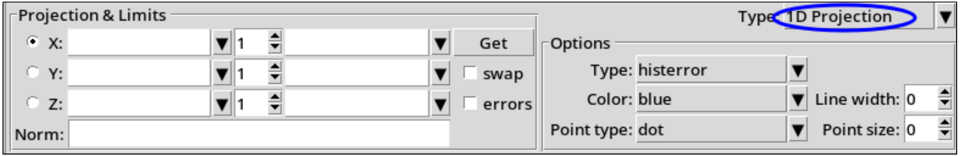
Low-T $\sim$ 7.375 s

Important! Inexperienced user might be tempted to use exaggerated low thresholds but should be advised that there are computing time repercussions associated with that choice.

Exercise: Cutoffs and thresholds (part 1)

Try to plot the other scored quantities (some might be empty, we will see why later).

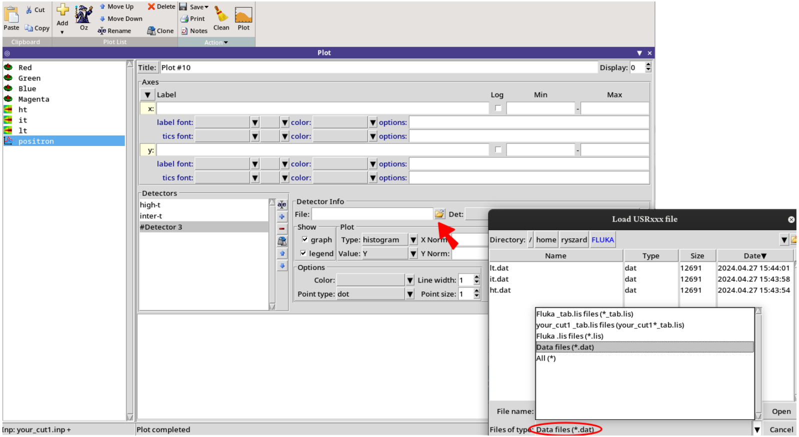
It is also possible to create 1D plots from USRBIN estimators too, simply by changing the projection type:



Follow this procedure for each of your other run's POSITRON results in separate plots via: Add (+) → USRBIN → plot as 1D projection.

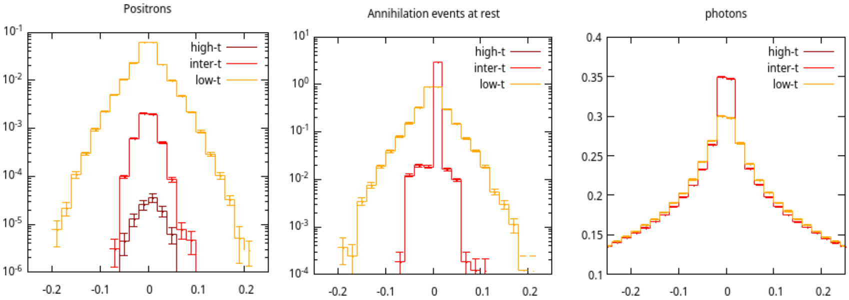
Exercise: Cutoffs and thresholds (part 1)

Once you have generated the three .dat files we can visualize them simultaneously, add a USR-1D and we will look for the .dat files and plot them one by one:



Exercise: Cutoffs and thresholds (part 1)

You should obtain a plot similar to the "Positrons" figure (left) below. You can repeat the process, and generate the two other plots for the annihilation events at rest and photons.



Exercise: Cutoffs and thresholds (part 1)

- As you can see, thresholds do change the results drastically:
  - A positron threshold of 600 keV results in the absence of annihilation events at rest (511 keV) and total lack of photons.
  - in the 500 keV case, the annihilation events are "artificially" localized, leading to an overestimated peak of photons as well as an unphysical distribution.

Important! Depending on the thresholds used, your results can be very different, both qualitatively and quantitatively. It is your responsibility to understand your simulation goals, and select the thresholds accordingly.

Online databases of particle ranges

Can be useful in order to set thresholds:
https://physics.nist.gov/PhysRefData/Star/Text/ESTAR.html
https://physics.nist.gov/PhysRefData/Star/Text/PSTAR.html

Exercise: Cutoffs and thresholds (part 2)

In this second part of the exercise we will tackle more challenging concepts, at a more **intermediate/advanced** level.

Copy both *.inp and *.flair files from the second part of this exercise transport_v2* to your work directory (or create new one) and change their name:

```
cp ../Exercises/Transport_exercise/transport_v2* .
mv transport_v2.inp yourtransport_v2.inp
mv transport_v2.flair yourtransport_v2.flair
```

Open the *flair* project file:

```
flair yourtransport_v2.flair &
```

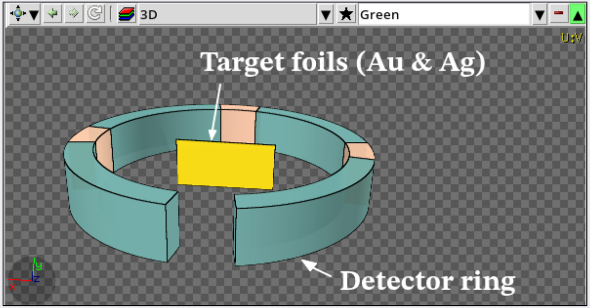
- Select “Input” in the flair interface, navigate to “Load” and fetch yourtransport_v2.inp

Exercise: Cutoffs and thresholds (part 2)

The input contains two thin target foils of gold and silver, with thicknesses 50 μm, surrounded by a ring with some detectors and an opening.

— We will first bombard these foils with a lower energy electron beam, and then, at a more advanced stage, we will use a more energetic beam of α-particles.

Inspect the input's geometry, on the top right view panel it should look like:



Exercise: Cutoffs and thresholds (part 2)

We propose to use a relatively low energy of electrons to see more clearly the fluence of photons and electrons heading backwards from the target.

- Create a 500 keV pencil-like e^- beam directed towards the target foils (positive in the z direction).

Then we should introduce some scoring cards:

- Create a USRBIN card to visualize the fluence of relevant particles.
- Prepare two USRBDX cards, scoring each electron and fluence entering the BACKS region from the INNER region (one way fluence scoring). Select 100 bins within the energy interval between 1-500 keV, and only one bin in solid angle. Calculate the approximate area value and go to the next slide once you are ready.

Exercise: Cutoffs and thresholds (part 2)

Your scoring setup should not be too different than this:

USRBIN		Unit: 21 BIN ▾	Name: ELECTRONS
Type: X-Y-Z ▾	Xmin: -40	Xmax: 40	NX: 80
Part: ELECTRON ▾	Ymin: -10	Ymax: 10	NY: 20
	Zmin: -20	Zmax: 140	NZ: 160
USRBIN		Unit: 22 BIN ▾	Name: PHOTONS
Type: X-Y-Z ▾	Xmin: -40	Xmax: 40	NX: 80
Part: PHOTON ▾	Ymin: -10	Ymax: 10	NY: 20
	Zmin: -20	Zmax: 140	NZ: 160
USRBDX		Unit: 24 BIN ▾	Name: BACKP
Type: Φ1,LogE,LinΩ ▾	Reg: INNER ▾	to Reg: BACKS ▾	Area: 87.27
Part: PHOTON ▾	Emin: 1E-6	Emax: 5E-4	Ebins: 100
	Ωmin:	Ωmax:	Ωbins: 1
USRBDX		Unit: 24 BIN ▾	Name: BACKE
Type: Φ1,LogE,LinΩ ▾	Reg: INNER ▾	to Reg: BACKS ▾	Area: 87.27
Part: ELECTRON ▾	Emin: 1E-6	Emax: 5E-4	Ebins: 100
	Ωmin:	Ωmax:	Ωbins: 1

Exercise: Cutoffs and thresholds (part 2)

Because the target layers are very thin (50 μm each) we will need to activate single scattering. This choice is rather CPU intensive, except for particles of very low energy (a few keV), which have a very short history anyway. In fact, for these cases the single scattering option is actually recommended

Use the option GLOBEMF and force #2 scatterings when crossing a boundary - you could increment it but do not run more than a couple of minutes.

Find in the manual the value of X in WHAT(4) .

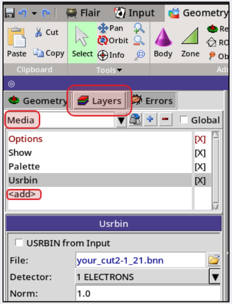
MULSOPT	X	2.	**GLOBEMF**

Save and run 3 cycles of 10^6 primaries.

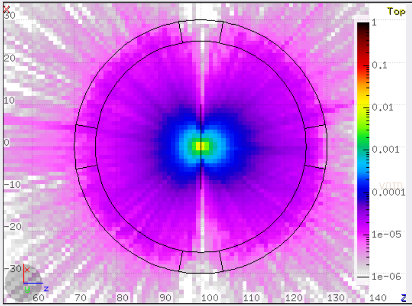
Exercise: Cutoffs and thresholds (part 2)

Once the run is done, attempt to visualize your USRBIN results in the flair geometry environment:

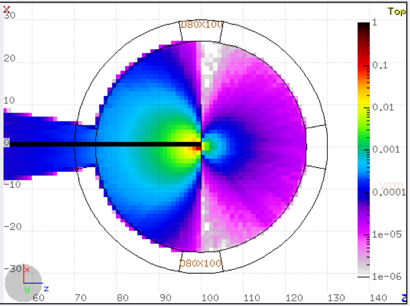
Possible example:



Photons



Electrons



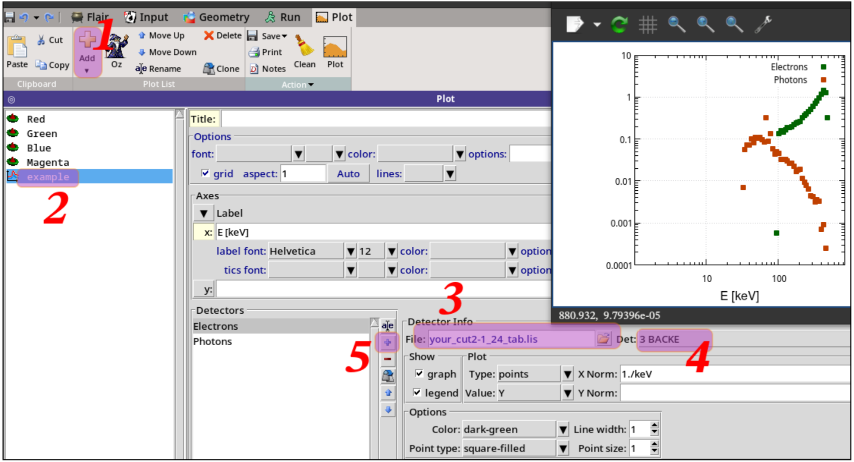
Exercise: Cutoffs and thresholds (part 2)

Now we will plot the USRBDX results, in the Flair plot tab:

1. Add a USR-1D
2. Select the newly created entry in the left panel
3. Browse for the `*.lis` file
4. Navigate to the detector (e.g. "BACKE")
5. Add a second series to be plotted

Exercise: Cutoffs and thresholds (part 2)

A simplified walkthrough with some suggestions and a plot



Exercise: Cutoffs and thresholds (part 2)

With our PRECISIOn Defaults we are not able to assess the behavior of electrons below 100 keV and photons below 30 keV. How to solve this?

Let us introduce a EMFCUT requesting a much lower cutoff at 1 keV instead,

EMFCUT	-1E-6	1E-6	Y	HYDROGEN	LASTMAT	**PROD-CUT**

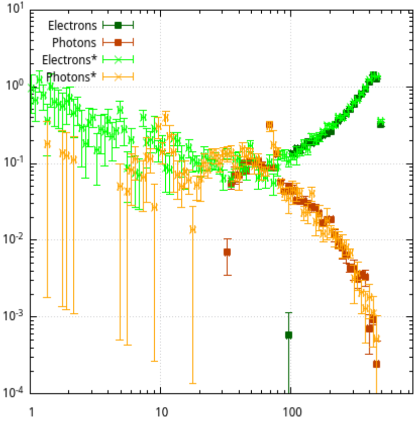
Important

The FUDGEM parameter in WHAT(3) needs to be defined, search the manual for further explanation and choose a Y value accordingly.

Save the input with a new name and adjust the primary particle number so that the run ends in ~ 5 minutes.

Exercise: Cutoffs and thresholds (part 2)

Once the run is completed, add more series (repeating step 5 in the previous example) with different names, use different properties to denote the various points (or lines) – **Find the units in the manual!**



Exercise: Cutoffs and thresholds (part 2 - Advanced)

Note to students

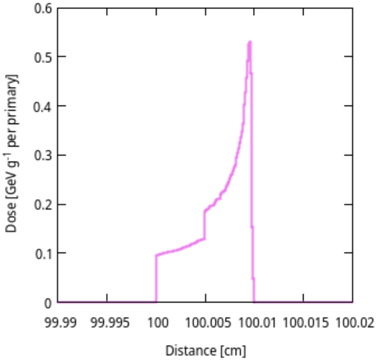
This part of the exercise is more challenging and is directed at students who have already some experience with FLUKA. Nevertheless, everyone can try it, and even if you are not able to finish it in the classroom you can always complete it later.

Let us convert our source of radiation to an $\alpha-$particle beam with 25 MeV

These $\alpha-$particles are much heavier and energetic than electrons and therefore we will see a rather different result with respect to the previous case, both in terms of the interaction with the foils as well as with the different detectors in the ring.

Exercise: Cutoffs and thresholds (part 2 - Advanced)

- Set a USRBIN scoring DOSE and 300 binnings traversing the targets from z=99.99 to z=100.2. Use 1 bin for X and Y (and 1 cm^2).
- Use 3 USRBDX cards to score α particle fluence entering the regions 'BACKS', 'D0X10' and 'D80X100' from the target direction.
- Run 3 minutes and plot the USRBIN results in a 1D projection (see right panel)



Question: Explain why the dose is value is null outside of the targets?

Question: Calculate the number of primary particles required to attain 1 Gy at the peak dose value (1 Gy = 1 J kg^{-1}).

Exercise: Cutoffs and thresholds (part 2 - Advanced)

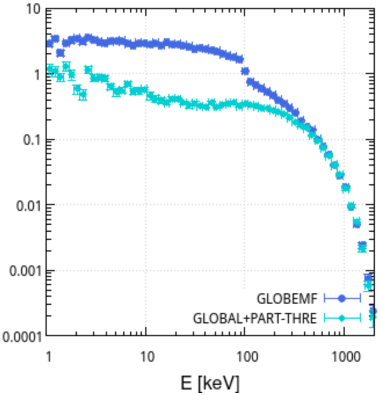
By looking at the USRBDX results you will be able to determine, for instance, which detector is receiving the most α radiation. But is your input really optimized?

- In the previous part of this exercise we included the option GLOBEMF in MULSOPT, but GLOBEMF restricts the input value use to the electromagnetic part, excluding the hadrons and thus our beam particles.
- The particle transport threshold for α-particles is still set at 100 keV, perhaps a lower value would be more advisable.

Check the manual which cards/option(s) are more applicable to our case.

Exercise: Cutoffs and thresholds (part 2 - Advanced)

- Re-run the input with a different name using GLOBAL in MULSOPT and a PART-THRE activated for α particles with kinetic energy cutoff at 1 keV.
- Plot the results of the two inputs for each of the different detectors – on the right side the 'D0X10' detector result is shown but it is also interesting to look into the 'D80X100', particularly if you can muster higher statistics.



Question: What differences do you observe?

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