Exercise: Neutronics

Exercise objectives

- Get familiar with the pointwise (PW) neutron treatment
- Plot pulse height spectra
- Observe the effect of $S(\alpha,\beta,T)$ from various materials
- Compare results with the groupwise (GW) treatment
- Fix some tracking artefacts on the recoil spectra

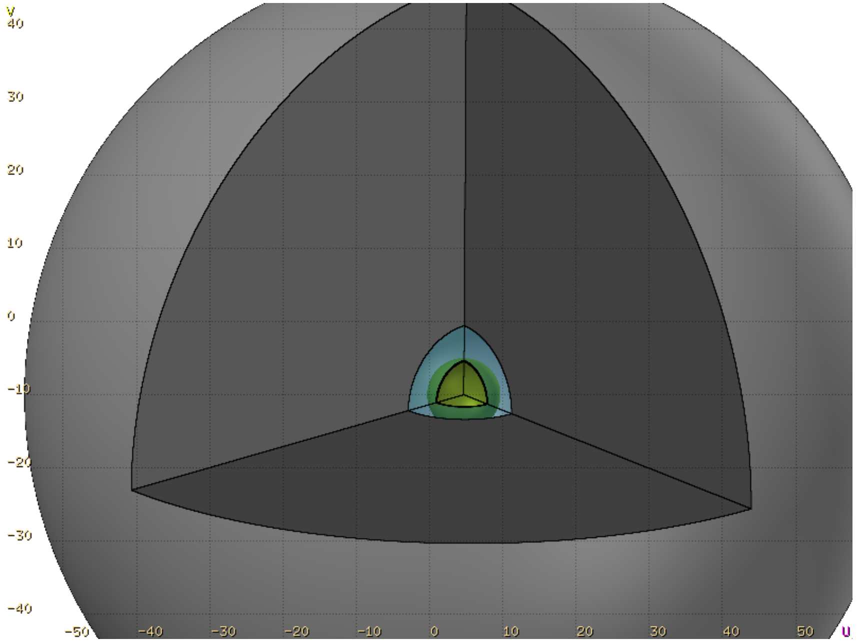
Description

- You will simulate a mockup fission chamber with an isotropic neutron source at the center.

- For didactic purposes the geometry will be simplified to an onion structure of concentric spheres

- You will need to create a parametric input (with #defines, #if, #else, #endif) to perform various runs.

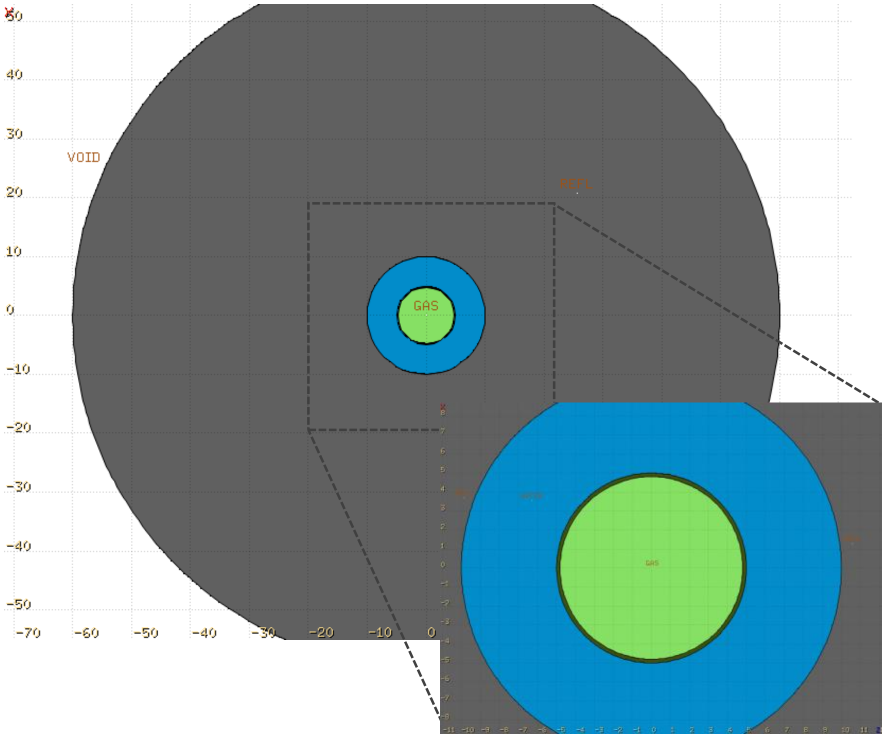
- In the input you will need to add the necessary source, geometry, materials, pointwise transport options and some scoring cards



1. General Settings

- Start with the **void** flair template (for the brave ones), otherwise use the provided flair file
- Add 3 #define cards, and **disable** them (in order to create parametric runs)
  - **PW** to select the pointwise vs groupwise
  - **PWSAB** to activate or disable the $S(\alpha,\beta,T)$
  - **FIX** to correct artefacts in the recoil spectra
- Source:
  - Particle: **Neutron**
  - Energy: **14 MeV**
  - Direction: **Isotropic**
  - Position: **at center (0,0,0)**

2. Geometry



Concentric spheres with radii:

- Butane Gas 4.8 cm from material library
- ^{235}U sample 5 cm custom material
- Water moderator 10 cm predefined
- Graphite reflector 60 cm predefined

Remarks:

- Normally, a fission ionization chamber will have a very thin fission sample (mg/cm^2) allowing the fission fragments to escape and ionize the gas. To speed up the calculation we are using a thick 2 mm ^{235}U sample, however almost all fragments will be stopped inside the sample. So we will score the pulse height inside the Uranium region

- The water is used to moderate and thermalize the neutron spectrum. With a neutron scattering length of ~6.7 mm, 5 cm are enough to thermalize a good fraction of the spectrum

- The graphite is used as neutron reflector. The optimum thickness of a reflector is equal to the diffusion length ($L^2 = l_a l_s/3$) which for graphite is of the order of L=48.5 cm (l_a=absorption length, l_s=scattering length)

3. Materials & Physics settings

- **Materials:**
  - **Butane**: can be found in the flair database
  - **U235**: add manually a **MATERIAL** card.
    Density: **18.95 g/cm^3**
    Do not forget to specify the Z=**92**, A=**235**
  - **Graphite:** use the default **CARBON** material of FLUKA
  - **WATER**: use the predefined material of FLUKA

- **Physics:**
  - Add two **PHYSICS** cards (needed for the residual nuclei scoring) to activate:
    - **COALESCE**nce
    - **EVAPORAT**ion with the **New Evap with heavy fragments**.

4. Transport

- Disable **EMF** in order to speed up the calculation.
- Add some **LOW-PWXS** cards under #if conditions to create 3 different settings

1. When **PW** is activated:
   - Activate the point wise treatment

   i. When also **PWSAB** is activated
      - Bind the S(α,β,T) “**graphite**” to material **CARBON**
        Note: Hydrogen is by default bound to h_water

   ii. else
      - **“unbind”** the S(α,β,T) from **HYDROGEN**
2. else (when GW is requested)
   - Use a **LOW-MAT** card to assign the “**235U, Uranium 235, 296K**” dataset to the **^{235}U material**

5a. Scoring

- **Pulse height spectra**

  add 2 **DETECT** cards for the **Uranium** sample region having **1024** channels each, with different energy ranges (since the histograms are linear in energy to see the features at various ranges)

  - Emin: **0.001** GeV Emax: **1.0** GeV
  - Emin: **0** GeV Emax: **0.001** GeV

- **Track length fluence detectors**

  add 5 **USRTRACK** cards with **log** histogram of **1000** bins each

  1. Region: **Uranium**, Particle **NEUTRON**, Emin: **1e-14** Emax: **0.1** GeV
  2. Region: **Uranium**, Particle **4-HELIUM**, Emin: **1e-5** Emax: **0.1** GeV
  3. Region: **Uranium**, Particle **HEAVYION**, Emin: **1e-5** Emax: **0.3** GeV
     Use an **AUXSCORE** card to filter only Cs-137 Z=**55** A=**137**
  4. Region: **Uranium**, Particle **HEAVYION**, Emin: **1e-5** Emax: **0.3** GeV
  5. Region: **Reflector**, Particle **NEUTRON**, Emin: **1e-14** Emax: **0.1** GeV

5b. Scoring

- **Boundary Crossing Detector**
  - One **`USRBDX`** detector for all **NEUTRONs** escaping from the **reflector** to **void**
    Emin: **1e-14** Emax: **0.1** GeV Bins: **1000** in **logE**

- **Fission fragments mass distribution**
  - One **`RESNUCLEi`** card for the **Uranium** region

- Optional: add the volume/surface of the detectors

6. Runs

- Create 3 types of runs
  - **pw**: using the point-wise neutron treatment without S(α,β,T) (only **PW** #define is enabled)
  - **pwsab**: using the point-wise neutron treatment with S(α,β,T) enabled both for Hydrogen and Graphite (both **PW** and **PWSAB** #defines are enabled)
  - **gw**: using the group-wise neutron treatment (**no #define** is active)
- Depending on your computer:
  - make a test short-run on all and see in the output the CPU time needed per primary
  - set that number of primaries such as to complete a minimum of 5 cycles in about ~5' time
  - if permitted by your computer add as many as possible spawned runs
- Observe the variation of time per primary for the different runs

- **Tip:** while waiting for the runs to finish, use the output of the short runs to prepare the plots

7. Plots

- For all plots you will combine the 3 runs (PW, PWSAB,GW).
  Use the same colors for each run per plot (e.g. PW:red, PWsab:purple, GW: blue)

- **DETECT**:
  - **pulse height**: create a USR-1D plot combining coarse and fine histograms for each type of run in a single plot

- **USRTRACK**:
  - Create one USR-1D plot per USRTRACK card with all the 3 runs

- Fission fragments:
  - Create one RESNUCLEi plot for each run plotting the **A** distribution
  - Create one combined USR-1D plot using the previous **RESNUCLEi** plots to combine the A distributions

- Observe the plots and try to explain the differences and the features you see

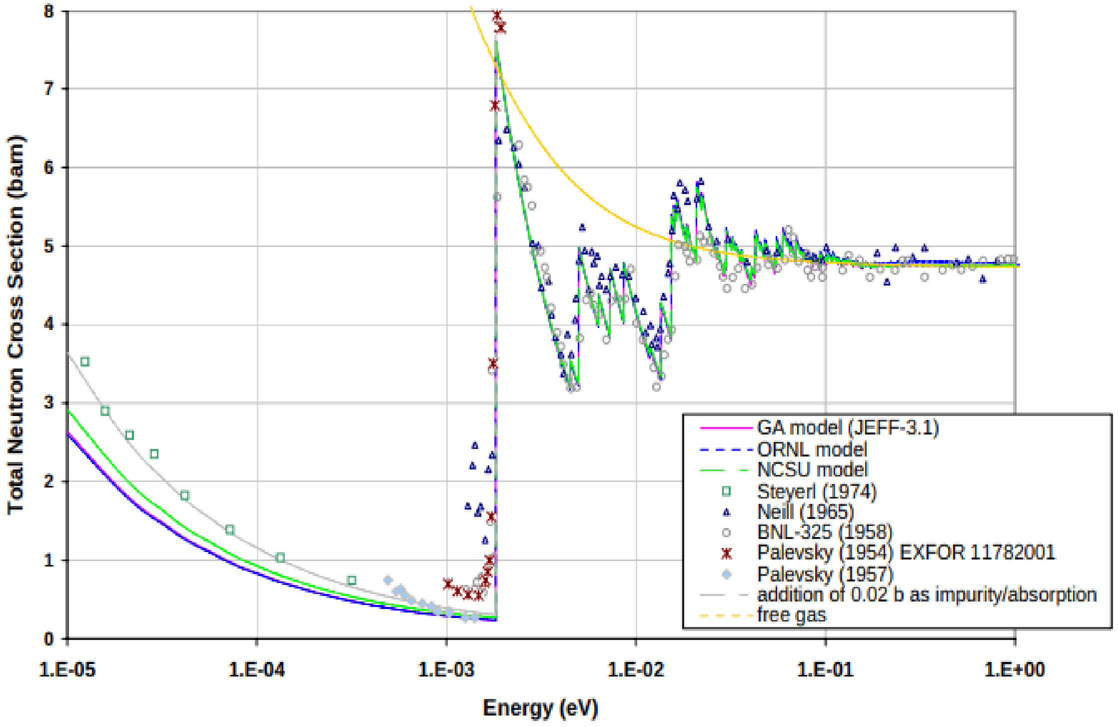
8. Correcting artefacts

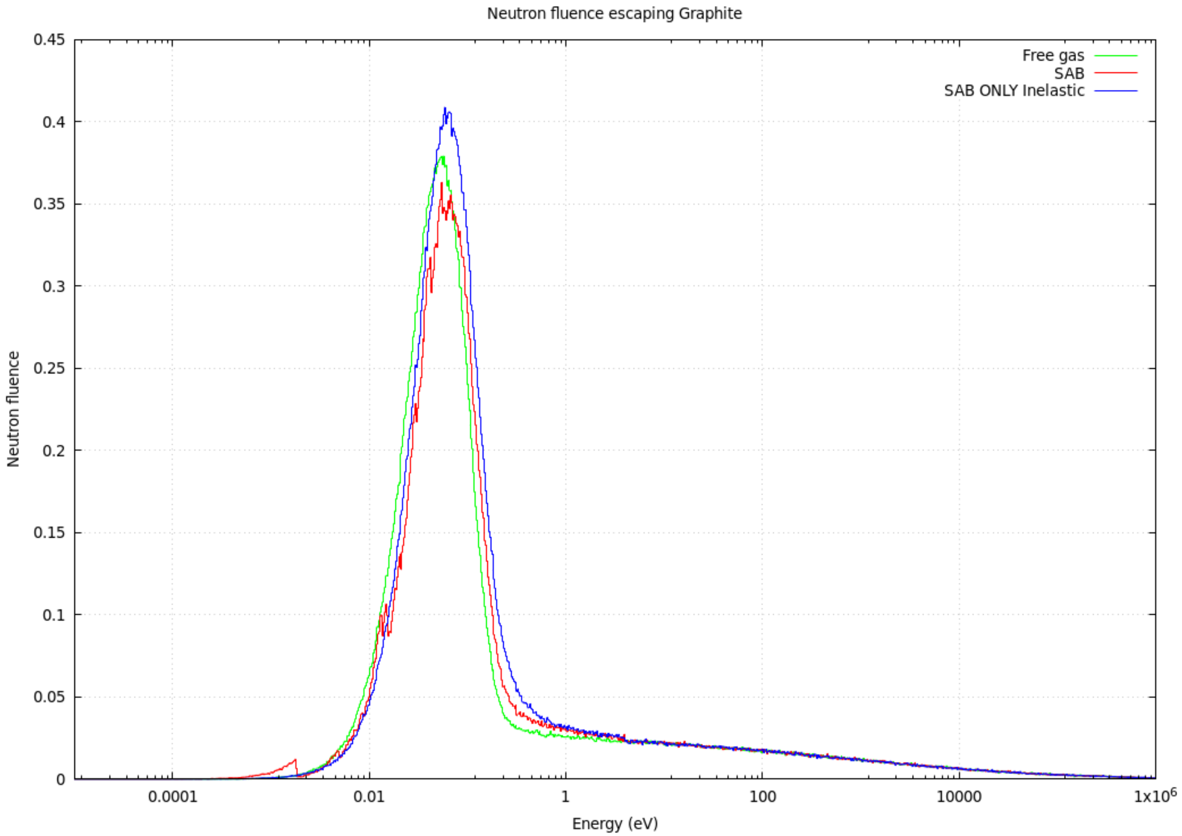
- You might have noticed some strange “aliasing” pattern in the ^{137}Cs fluence and Heavy Ion fluence plots.

- This is caused by the “coarse” handling of the default approximate ranging out algorithm in FLUKA.

- To correct it you need to add a new run named **FIX**, activating also the **PW/PWSAB** where you introduce the following cards under an `#if` **FIX** ... `#endif` condition
  - `FLUKAFIX`: with at most **1%** maximum energy loss for the **U235** material
  - `IONTRANS`: enable the accurate ion transport
  - `PART-THRES`: lower the **4-HELIUM** transport threshold to the minimum of **1 keV**

Example S(α,β,T) on Graphite





https://www-nds.iaea.org/publications/indc/indc-nds-0475.pdf

https://fluka-forum.web.cern.ch/t/4528/7

FLUKA