



Exercise 7: Activation

Advanced FLUKA Course

Definition of the problem

Goal

Plan an intervention to remove an irradiated target (after one week of decay)

Calculate the radionuclides inventory prior to its disposal as radioactive waste (after 10 y)

Beam characteristics

- 1 GeV proton beam (pencil beam)
- Irradiation of one month with a beam intensity of 1×10^{13} pps

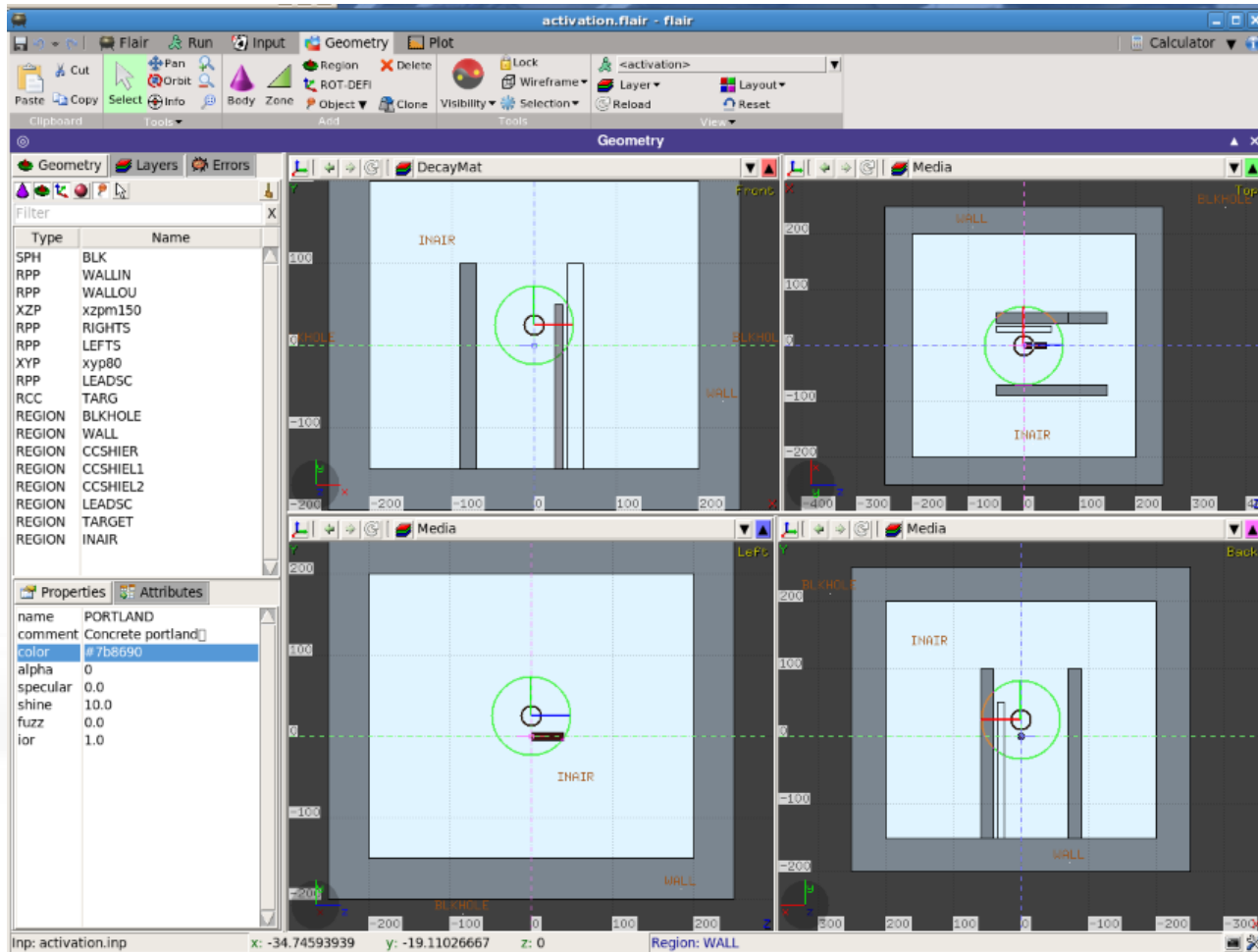
Geometry (seen next slide for illustration)

- Cylindrical stainless steel target (40cm long, 5cm in radius)
- Some cobalt in the SS316LN composition has been added (1 % mass fraction)
- The target is inside a bunker with 50 cm thick walls. The dimension of the bunker is 400 cm along the z-axis (target at the middle), 400 cm laterally and with a height of 350 cm (the target is 150 cm above the floor level)
- Two concrete shieldings are installed on each side of the target. They are 20 cm thick, extend along 200 cm in the z direction (starting 50 cm before the target) and they are 250 cm high
- One lateral shielding is made of two parts (split with a plane). The first 130 cm can be removed with a crane if access to the target is needed

Problem

- The target is water cooled. Following a leak the target will be removed with a crane and replaced with a new one. The lateral shielding wall is partially removed. You can install a lead screen on the side of the target. Assess the shielding effect provided by the screen.
- Calculate the radionuclides inventory after 10 years of cooling time (the target is a radioactive waste)

Geometry (I)



It is poorly shielded (the one who designed it did not attend the FLUKA course !)

Geometry (II)

```
* Bunker wall and floor
RPP WALLIN      -200.0 200.0 -151.0 200.0 -200.00 200.0
RPP WALLOU      -250.0 250.0 -200.0 250.0 -250.0 250.0
XZP xzpm150     -150.
* Lateral shielding
RPP RIGHTS      -90. -70. -151.0 100.0 -50.0 150.0
RPP LEFTS       40. 60. -151.0 100.0 -50.0 150.0
* plane to cut the shielding in two parts
XYP xyp80       80.0
* Lead screen for the decay part
RPP LEADSC      25.0 35.0 -151.0 50.0 -50.0 50.0
* Copper target
RCC TARG        0.0 0.0 0.0 0.0 0.0 40.0 5.0
```

The bodies used to define the geometry

GEOMETRY (III)

```
BLKHOLE      5 +BLK -WALLOU
* Walls of the bunker and shielding on the side
WALL         5 | +WALLOU -WALLIN -xzpm150
              | +WALLOU +xzpm150
CCSHIER      5 | +RIGHTS -xzpm150
CCSHIEL1     5 | +LEFTS -xzpm150 -xyp80
CCSHIEL2     5 | +LEFTS -xzpm150 +xyp80
* Lead screen for the decay part
*
LEADSC       5 +LEASC -xzpm150
* Target
TARGET       5 +TARG
* Air in the bunker
*
INAIR        5 +WALLIN -xzpm150 -RIGHTS -LEFTS -TARG -LEADSC
END
```

The geometry

Geometry (IV)

Setting the material assignment for the prompt and decay part

- Open the activation-to-complete (.inp or .flair) file, the geometry and most of the input has been written for you
- Make the material assignment for two cases (use a define "open-screen"):
 - 1) The shielding is in place
 - 2) The shielding is open (removed) and the lead screen is installed
 - (3) if you have extra time, open the shielding but don't "install" the lead screen)
- Create a layer in the flair geometry editor (call it DecayMat) to allow you to visualize the Media (material assignment) in the decay part of the transport. It should help to verify that the previous step is correctly done

Radioactive decay cards

- Complete the irradiation profile card to define an irradiation profile of one month with 1×10^{13} pps
- Complete the cooling time card : one week and ten years (use the FLAIR style instead of converting to seconds)
- Check for the presence of the PHYSICS cards for activation calculations (generalized evaporation model and coalescence)
- Kill the electromagnetic cascade in the prompt part of the calculation (we assume that photonuclear reactions don't have a significant contribution for our application)
- Check the production and transport threshold for photons and electrons/positrons. Are they relevant for the energy of E.M. particles from radioactive decay ?

Scoring cards

- Vertical and horizontal dose rate maps for one week of cooling time have been defined
- Change the default fluence to effective dose coefficients to "EWTMP" using the AUXSCORE cards for the two detectors
- Look in the input, residual nuclei are scored after 10 years using two methods
 - 1) with a region based USRBIN (ACTIVITY)
 - 2) with a RESNUCLE card
 - 3) with several region based USRBIN (ACTIVITY) and filter (AUXSCORE) a few radionuclides (H-3, Co-60, Mn-54...)

Do you think the methods are equivalent ? Which one is the best ?

Filtering with fluscw (I)

- Complete the fluscw-incomplete.f routine to score the contribution of particles coming from the radioactive decay of Co-60 only
- We will test it using a USBDX card and a USBIN

```
ISCRNG = 1 --> Boundary crossing estimator
ISCRNG = 2 --> Track length binning
ISCRNG = 3 --> Track length estimator
ISCRNG = 4 --> Collision density estimator
ISCRNG = 5 --> Yield estimator
```

- Hint: We use the flag laztrk (you need to include (TRACKR)) to identify the parent radioactive isotope ($\text{laztrk} = A + 1000Z + 1000000 * m$). Define VALUE to score only the contribution from Co-60 decay
- We use the name of the estimator (for example starts with "IS" but you can change the logic to A-Z...) to select the detector to which the filter will apply

Filtering with fluscw (II)

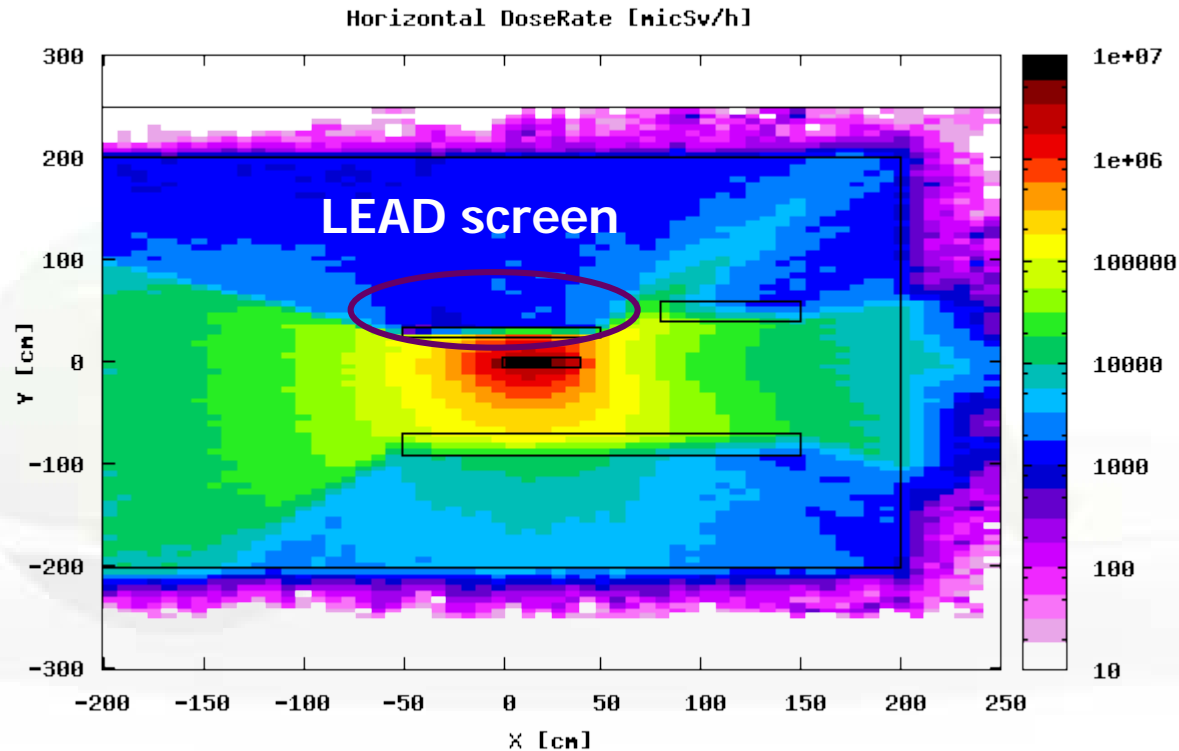
```
INCLUDE '(USRBDX)'  
INCLUDE '(USRBIN)'  
INCLUDE '(TRACKR)'
```

TITUSX(JSCRNG)(1:2) first two letters of the SDUM of the current estimator for USRBDX for which fluscw.f is called

TITUSB(JSCRNG)(1:2) same thing for a USRBIN detector

- Don't forget USERWEIGH (check it is there in the input) !
- We Score a residual dose rate map (USRBIN card) after one week (or one year) of cool down time coming from the radioactive decay of Co-60 only
- We score using two USRBDX detectors, the energy spectrum of PHOTONS exiting the target (use a linear energy binning with 10 keV bins from 0-3 MeV for example):
 - 1) Spectrum from the decay of all particles.
 - 2) Spectrum from the decay of Co-60 only. Compare the two.

Horizontal view of the residual dose rate



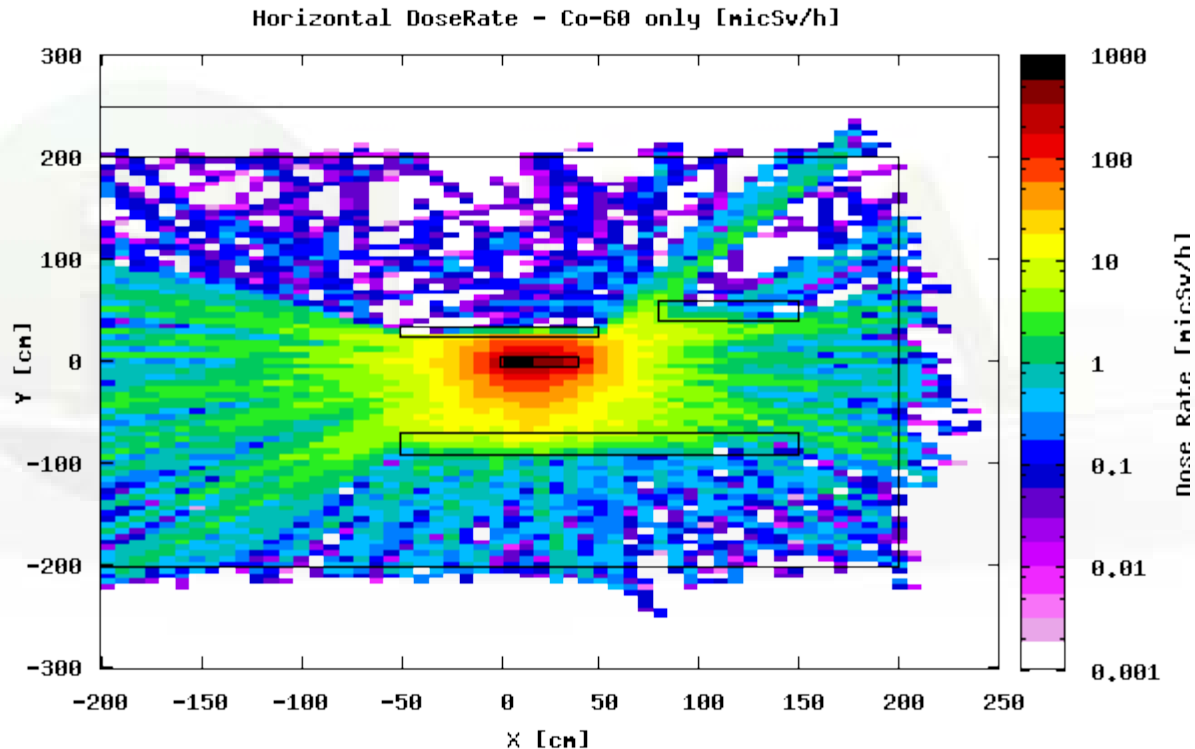
Only one week of cooling

On which side would you prefer to work?

Would you recommend installing the lead screen?

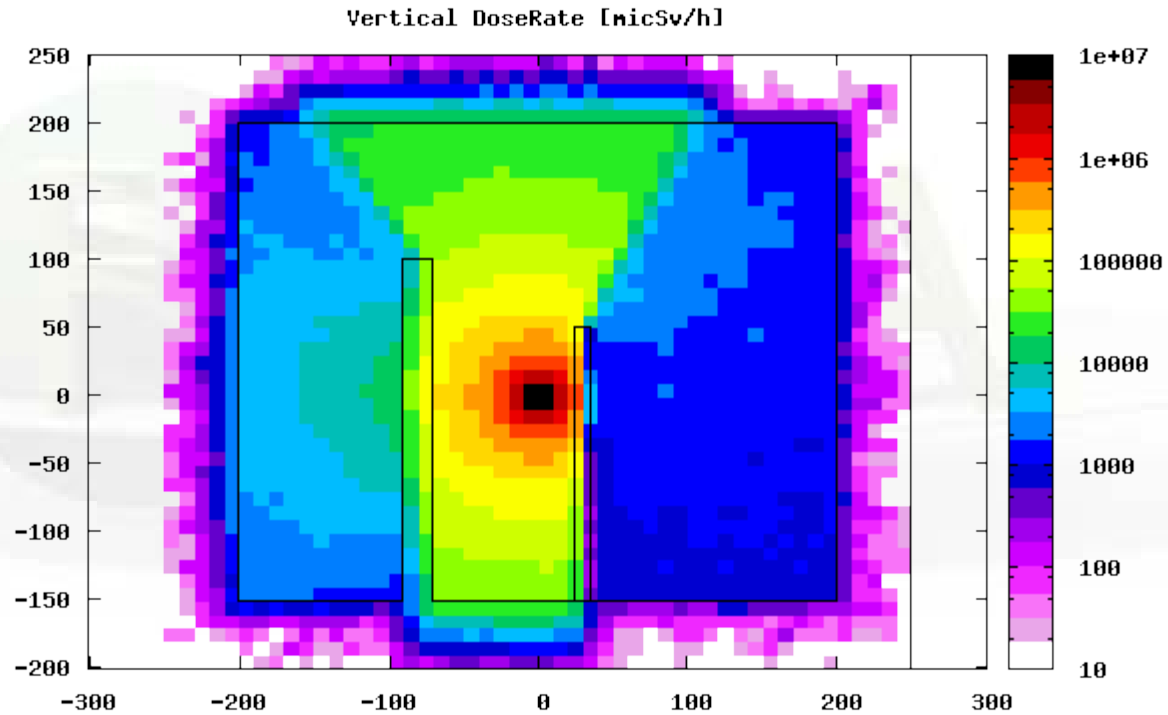
Filtering: dose rate due to decay of Co-60

The scale has been changed



Filtering all isotopes but Co-60 (sensitivity to cobalt content in steel for long cooling times)

Vertical view of the residual dose rate



RESNUCLE and some comments

- Open the RESNUCLE results (sum.lis file for example)
- Transform the USRBIN card (region based) to ascii and open it as well
- Compare the two results. Convince yourself that the two approaches are equivalent (RESNUCLE has the advantage of listing all radionuclides individually)
- You could have also used a cylindrical binning overlapping exactly with the target with a single bin (or several to look at the spatial distribution) and obtain the same results.
- The latter could be useful to look at the spatial distribution ("hot spots")
- In the latter case however, the normalization to the volume of the scoring bin (overlapping exactly the target in that case) would have been computed by FLUKA

Filtering USRBDX by parent isotope (Co-60)

What are those two peaks ?

