Deposited Energy and Dose scoring output in FLUKA

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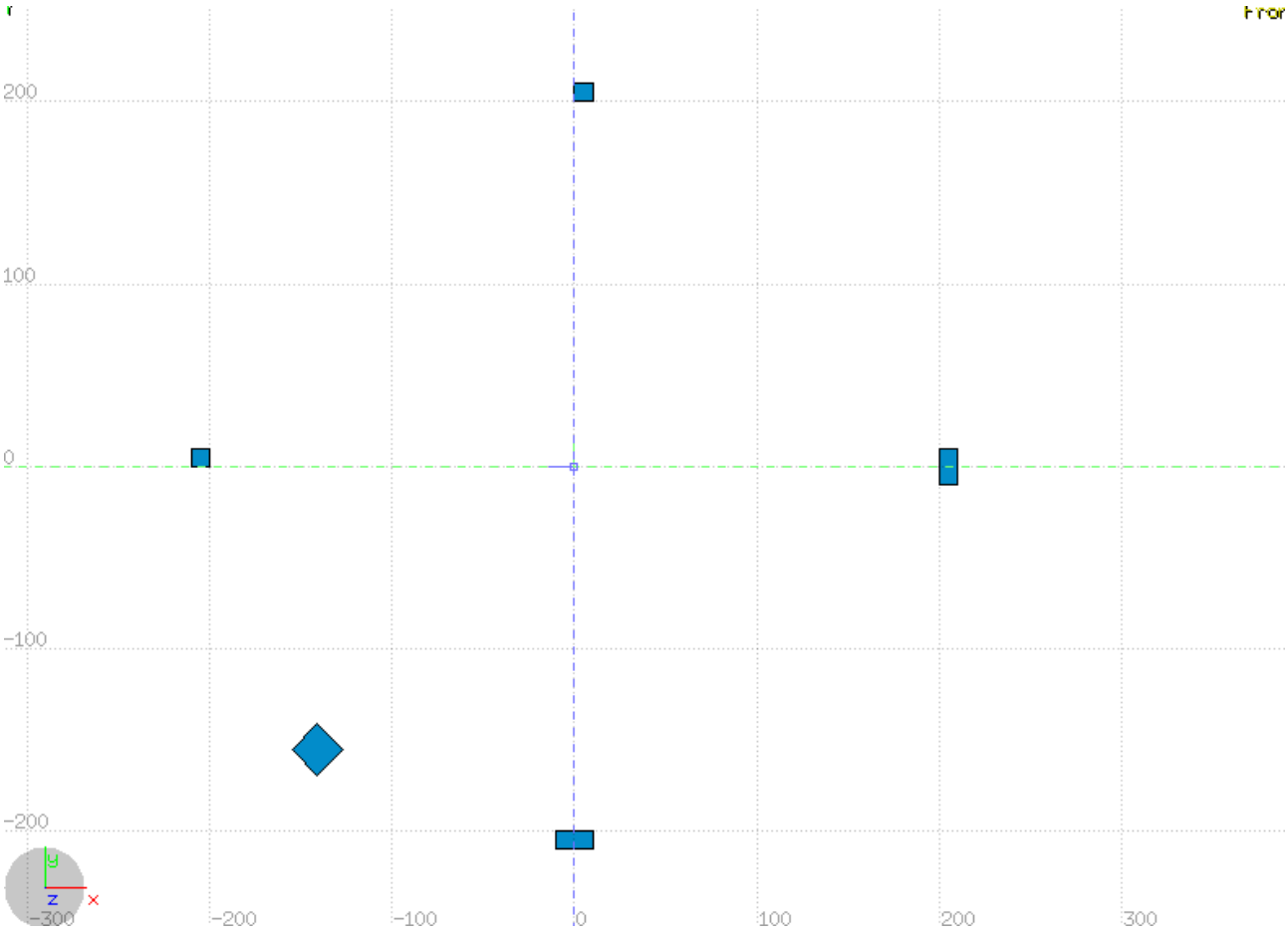
January 2013

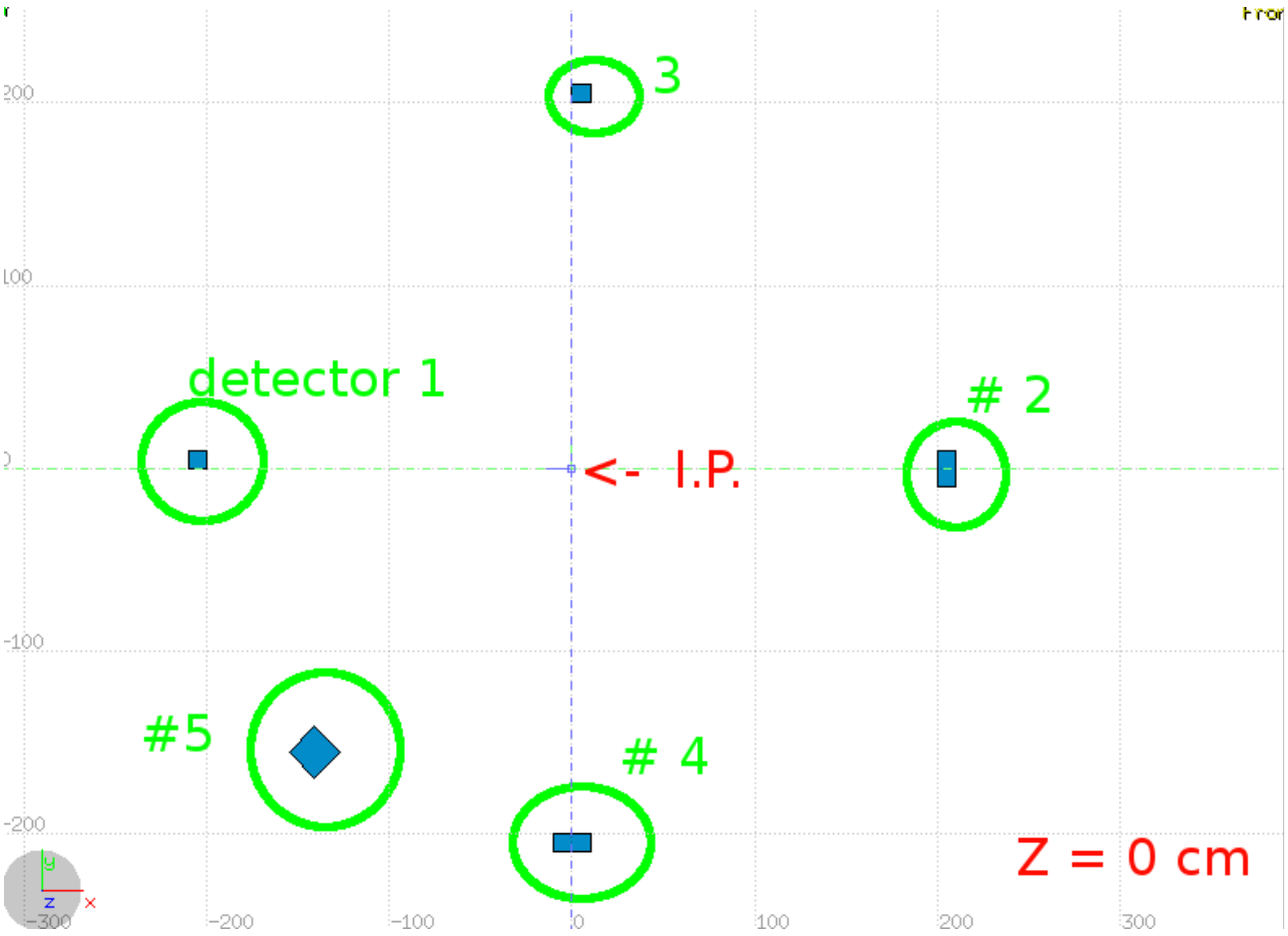
The purpose of this brief report is to have a better understanding about FLUKA scoring output, its units and normalization factors.

It was created a simple geometry with 5 different detectors for measuring DOSE and DEPOSITED ENERGY. There are two proton beams travelling by Z axis but in opposite direction (x=0 and y=0 , the same coordinate system as CMS detector). The interaction point (IP) is at x=0, y=0 and z=0.

All the detectors are located in different positions but they all have the same Z=1000 cm and a Radius R=200 cm. Their material is WATER.



Picture 1



Picture 2

Note that the detectors have several volumes (1000 cm^3 , 2000 cm^3 and 4000 cm^3)

		Position	
Detector	**Volume (cm3)**	**Radius (cm)**	**Z (cm)**
1	1000	200	1000
2	2000	200	1000
3	1000	200	1000
4	2000	200	1000
5	4000	200	1000

Table 1

USRBIN scoring was used to get the results, defining by **REGION** and by **X-Y-Z** .
It was simulated in lxplus using 500000 primaries/events in order to get good statistics.

Using USRBIN scoring definition by **REGION** you just need to select the name of your volume as a label of an object, for example: “my_detector1”

Using USRBIN scoring definition by **X-Y-Z** you need to tell FLUKA the coordinate intervals of your binning, for example:

xmin: -210 xmax: -200
ymin: 0 ymax: 10
zmin: 1000 zmax: 1010

RESULTS (1):

FLUKA OUTPUT, USRBIN BY REGION

		USRBIN by region		Comparison
Detector	Volume (cm3)	Deposited Energy	Dose	Dep. Ene. / 7.13E-05
1	1000	7.13E-005	7.13E-005	1.00
2	2000	1.30E-004	1.30E-004	1.83
3	1000	7.28E-005	7.28E-005	1.02
4	2000	1.46E-004	1.46E-004	2.05
5	4000	2.84E-004	2.84E-004	3.98

Table 2

Looking at **Table 2**, we find that both results, DEPOSITED ENERGY and DOSE depend on the volume of the detector.

As DEPOSITED ENERGY is and extensive quantity (the more the volume, the more the deposited energy), so those results seem to have sense: If we have detector #2, which is twice the volume of detector #1, we expect twice the DEPOSITED ENERGY in detector #2.

As DOSE (TOTAL IONIZING DOSE) is defined by :

$$DOSE = \frac{DEPOSITED\ ENERGY}{MASS}$$

, those results doesn't seem to have any sense!
But if we play with numbers and we divide the DOSE value by the volume of the detector, we get almost the same result:

Detector	Volume (cm3)	FLUKADose	FLUKA Dose / Volume
1	1000	7.13E-005	7.1303E-008
2	2000	1.30E-004	6.518E-008
3	1000	7.28E-005	7.2759E-008
4	2000	1.46E-004	7.316E-008
5	4000	2.84E-004	0.000000071

Table 3

We are expecting the same value of DOSE in all detector, does not matter how much bigger the detector is (assuming the same material and positions). DOSE is an intensive property.

RESULTS (2):

FLUKA OUTPUT, USRBIN BY X-Y-Z

		USRBIN by XYZ	
Detector	**Volume (cm3)**	**Deposited Energy**	**Dose**
1	1000	7.13E-008	7.13E-008
2	2000	6.52E-008	6.52E-008
3	1000	7.28E-008	7.28E-008
4	2000	7.32E-008	7.32E-008
5	4000	7.10E-008	7.10E-008

Table 4

Looking at **Table 4**, we find that both results, DEPOSITED ENERGY and DOSE **DO NOT** depend on the volume of the detector.

As we know that DOSE is an intensive property we can think that dose might be OK. Let's compare "DOSE" in **Table 4** with "FLUKA_DOSE" in **Table 3,** They are the same!.

Again, playing with numbers and DEPOSITED ENERGY , if we multiply FLUKA_Deposited_energy times the volume of the detector we will get a quantity which depends linearly on the volume. That is what we expect on DEPOSITED ENERGY. See Table 5

		USRBIN by XYZ	
Detector	**Volume (cm3)**	**Deposited Energy (FLUKA)**	**Dep. En. * Volume**
1	1000	7,13E-008	7,13E-005
2	2000	6,52E-008	1,30E-004
3	1000	7,28E-008	7,28E-005
4	2000	7,32E-008	1,46E-004
5	4000	7,10E-008	2,84E-004

Table 5

Now, let's compare **"Dep. En. * Volumen"** in Table 5 with **"Deposited Energy"** in Table 2. THEY ARE THE SAME!

Now, let's see some definitions in FLUKA manual:

http://www.fluka.org/fluka.php?id=man_onl&sub=84

...

5) Energy deposition will be expressed in GeV per cm3 per unit primary weight. Doses will be expressed in GeV/g per unit primary weight. To obtain dose in Gy, multiply GeV/g by 1.602176462E-7

...

13) The results from USRBIN are normalised per unit volume and per unit primary weight, except for region binnings and special user-defined binnings which are normalised per unit primary weight only, for DPA, which are given as number of displacements per atom per unit primary weight, averaged over the bin volume, and for dose equivalent, expressed as pSv per unit primary weight. In case symmetries are requested, proper rescaled volumes are taken into account for normalisation (that is, an extra factor 2 is applied to the volume if symmetry around one plane is required, 8 if the symmetry is around the origin)

CONCLUSIONS:

- If we use USRBIN card definition BY REGION:
  - DEPOSITED ENERGY is in GeV and we take the value as is.
  - DOSE, **we must divide** this value by the volume of the detector and the result will be in GeV/g.

- If we use USRBIN card definition BY X-Y-Z:
  - DEPOSITED ENERGY, **we must multiply** this value times the volume of the detector. Once we do that, the result will be in GeV.
  - DOSE is in GeV/g, and we take the value as is.

- To obtain dose in Gy, multiply GeV/g by 1.602176462E-7

- NOTE that in this example the value of deposited energy in 1 cm^3 of water is the same of the value of the dose in 1 cm^3 of water. It is because the density of water equals 1 g/(cm^3)