PET scan simulation

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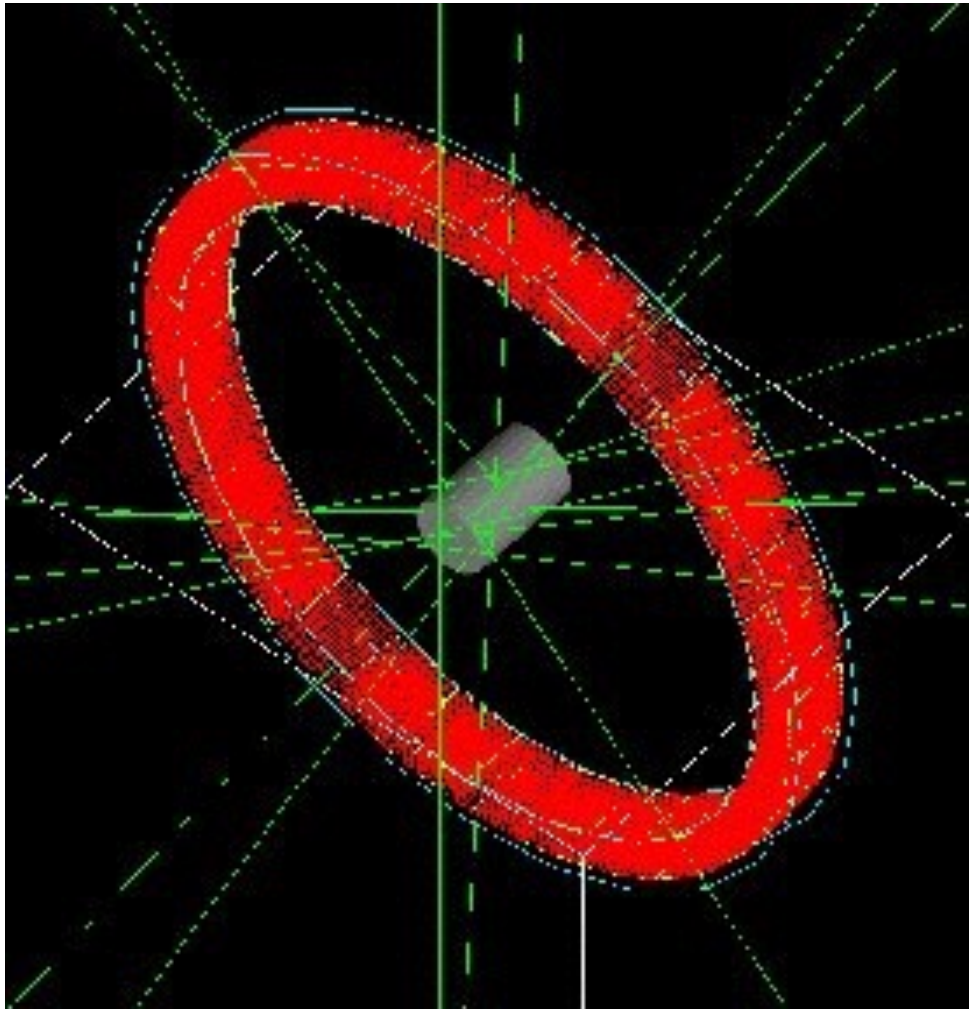


Fig 1: PET camera simulation in gate by cylindrical phantom

What is PET?

Positron emission tomography (PET), is a nuclear medicine and molecular Imaging method that using electron positron annihilation to create an acute image from cells. The source of radiation inject to the test subject. By radioisotope decaying, positron annihilate with electrons occur and emitting two 511 Kev photons that receding each other by 180 angle. PET create image by detecting photons that comes from subject.

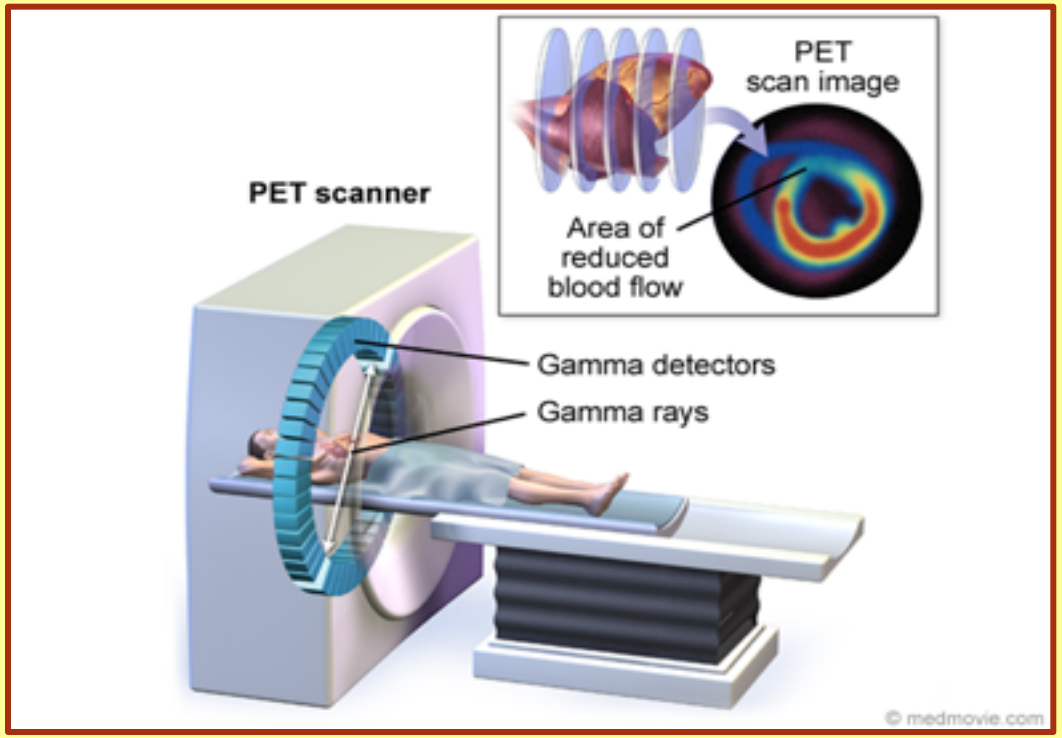


Fig 2: Patient and PET scan charts

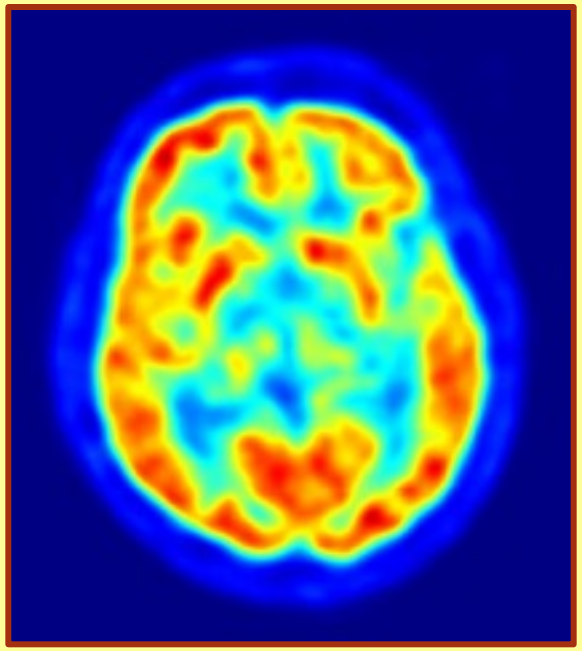


Fig 3: Brain PET scan output

PET Scan process steps

- Producing radioisotopes in cyclotron (commonly F-18 FDG).

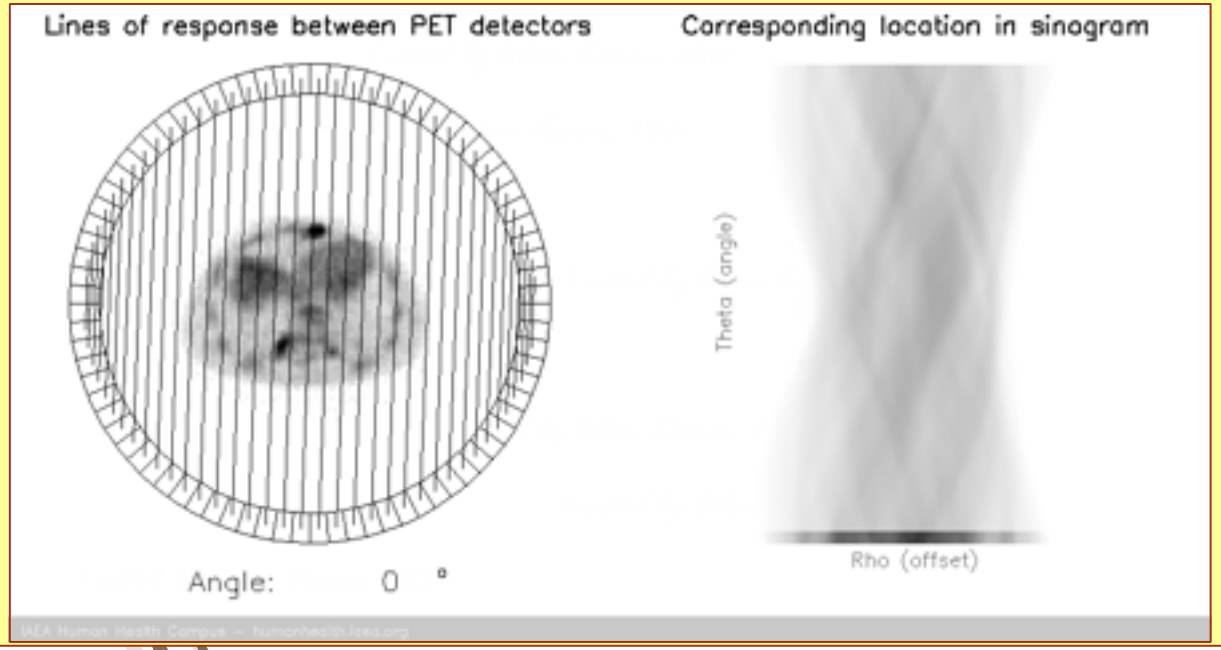
Half time is about 110 min

- Radioisotopes injection. To vein. Why?
- PET Scanning 1 hour after injection(depend to organ)

PET must be acute because it is molecular Imaging

Fig 4: cyclotron

Fig 5: injection



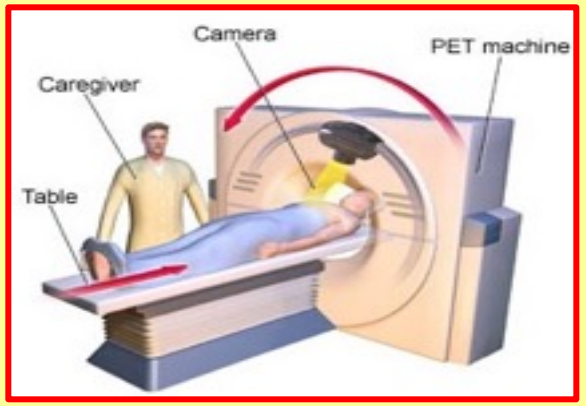


Fig 6: PET Scanning

How radioisotopes are working?

Cell need energy and cancers cells need more energy because of repopulation processed so they need more energy source . glucose is best source of energy for cells. So we should marked these molecules by radioisotopes. Cells using glucose and deposit radioisotopes. These radio isotopes emitted positron. Positron after 2-12mm collide with an electron and then annihilation occur

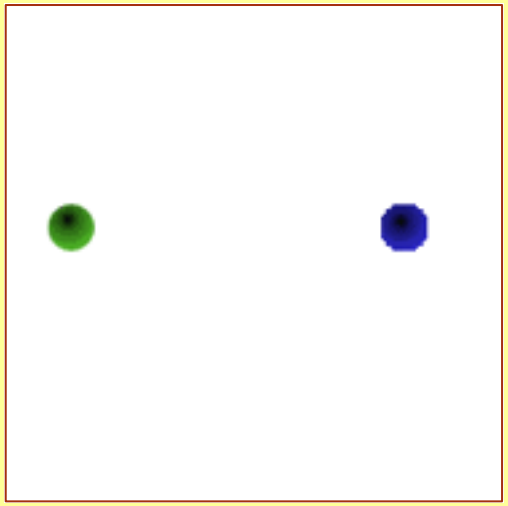


Fig8: Annihilation

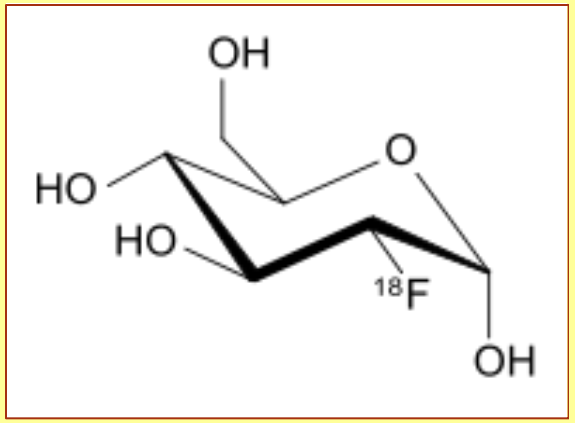


Fig 9:Fluorodeoxyglucose (^{18}F)

Basic type of PET

There are two basic type of PET

- Small animal PET : small animal PET using for pre-clinical cases like rat, for engineering and physicist is good to test their novelty in miniature size, physicist interested in this primary type because data acquisition is easier and prices is cheep because amount of detectors are less than large size

- Usual PET : this is ordinary PET, scientist using PET to diagnosing diseases and studying function of organs like brain. It is reasonable that before you make your PET, first try its miniature size.

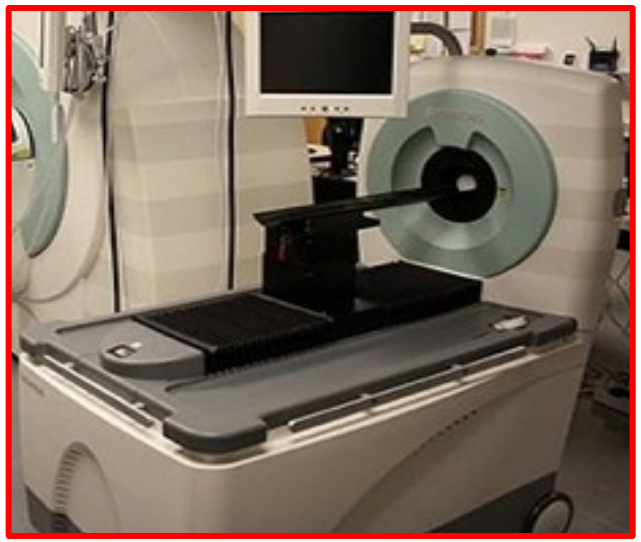


Fig 10: small animal PET

Fig 11: PET

Simulation

1 step before

There are different parameters in PET camera to rich best results. Like scintillation crystals, detectors ring geometry, coincidence etc**.** Today most of studies in this field, focused on geometry of PET scans detectors rings and type of scintillation crystals. For researcher who they are studying on PET scan system, is difficult to build a PET scan system at first to do their research on it directly. The solution is simulation. Gate simulation software is a strong tool that gives a lot of abilities to researcher to design PET scans detector rings, material and shapes of scintillation detectors, phantom, source, calculating parts such coincidence and electronic noises etc.

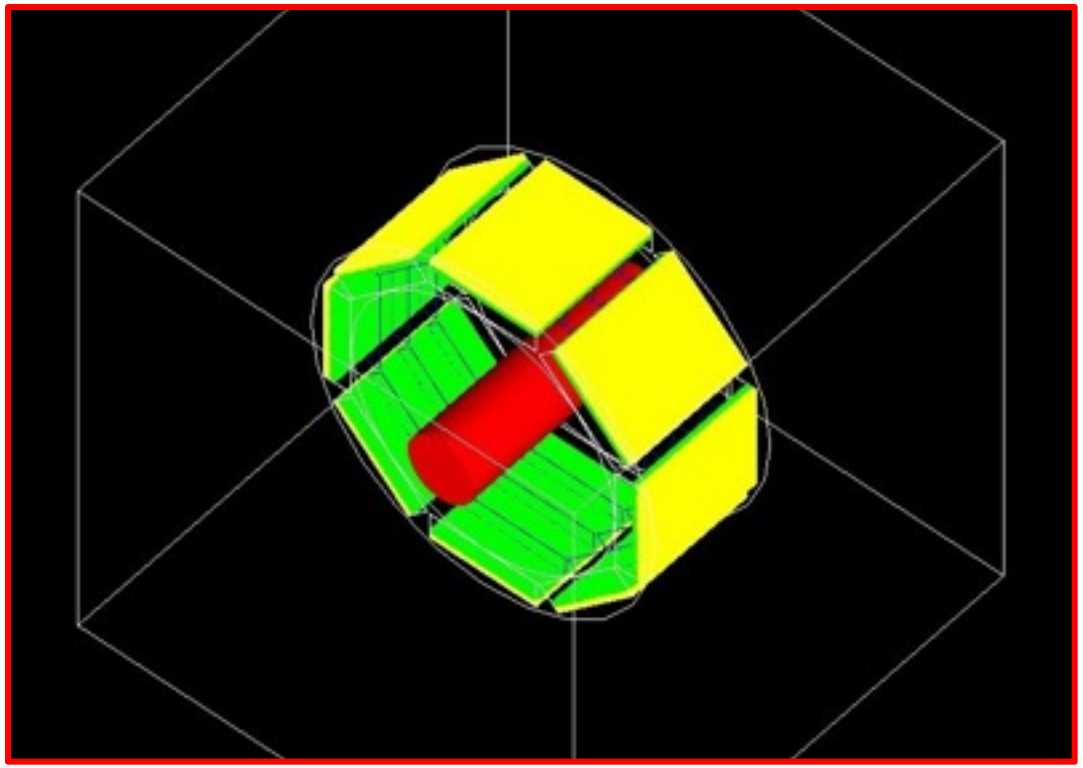
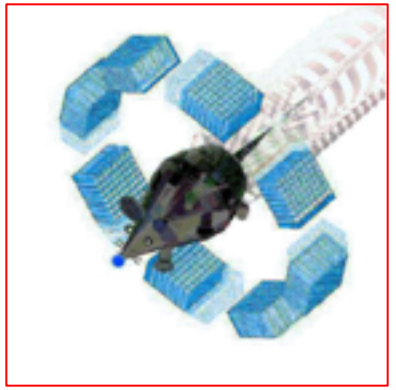


Fig12: Gate viewer include detectors and phantoms.

7 Gate

Gate is a simulation software based on GEANT4. it has a material database that you can define every kind of materials by knowing its atomic numbers and percentage. After defining all part of detectors and phantom in Gate environment, you should run your simulation to get the data, then according your purpose you can analyze them to rich to the results.

Simulation in Gate environment is like writing program inside it. There is a reasonable assortment for that, first you should define materials database for your system, then by creating a world begin to design your system from outside to inside.



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```
#      S O U R C E
/gate/source/addSource twogamma
/gate/source/twogamma/setActivity 100000. becquerel
/gate/source/twogamma/setType backtoback

# Position
/gate/source/twogamma/gps/centre 0. 0. 0. cm

# particle
/gate/source/twogamma/gps/particle gamma
/gate/source/twogamma/gps/energytype Mono
/gate/source/twogamma/gps/monoenergy 0.511 MeV

# TYPE= Volume or Surface
/gate/source/twogamma/gps/type Volume

# SHAPE= examples Sphere or Cylinder
/gate/source/twogamma/gps/shape Cylinder
/gate/source/twogamma/gps/radius 0.5 mm
/gate/source/twogamma/gps/halfz 25 mm
```

Fig 13: sample commands for define source in Gate

How is Gate working?

One sample:

Step 1 → **Define your database** → Visualization → system → Defining geometries → crystals → Repeat

At this step we should be careful about geometries and materials, specially for crystals

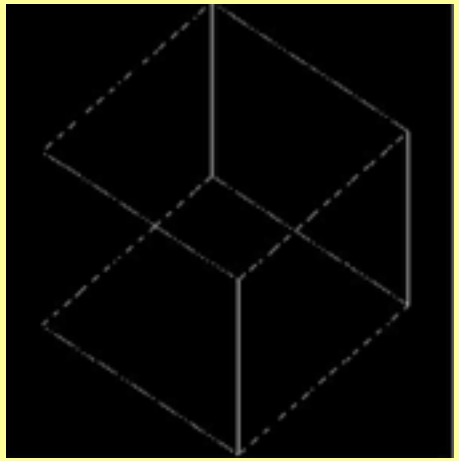

Fig14: World

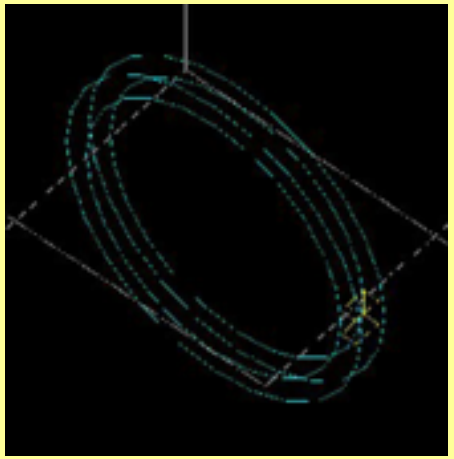

Fig15: Geometry

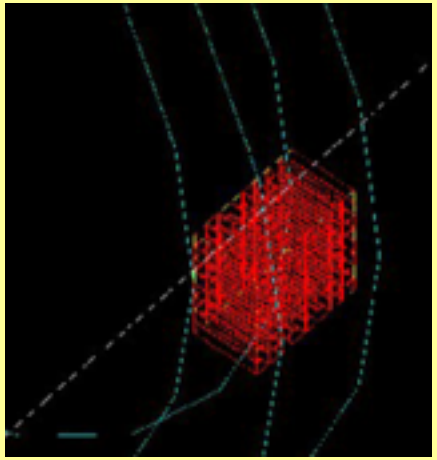

Fig16: Crystals loaded

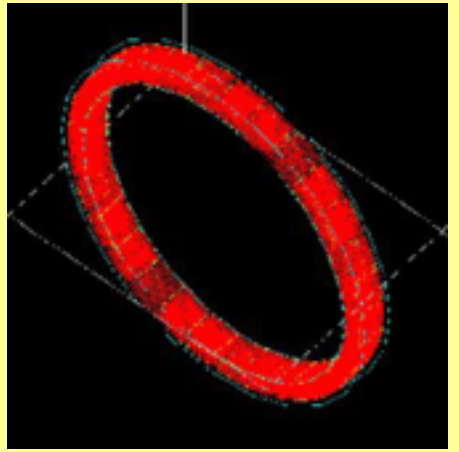

Fig 17:Detectors ring

Second steps

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Phantom → **physics processes** → INITIALIZE → Coincidences → **acquisition** → run

- Threshold
- Blurring: to get real date not ideal one

```
# ENERGY BLURRING
/gate/digitizer/Singles/insert blurring
/gate/digitizer/Singles/blurring/setResolution 0.19
/gate/digitizer/Singles/blurring/setEnergyOfReference 511. keV

# ENERGY WINDOW
/gate/digitizer/Singles/insert thresholder
/gate/digitizer/Singles/thresholder/setThreshold 350. keV
```

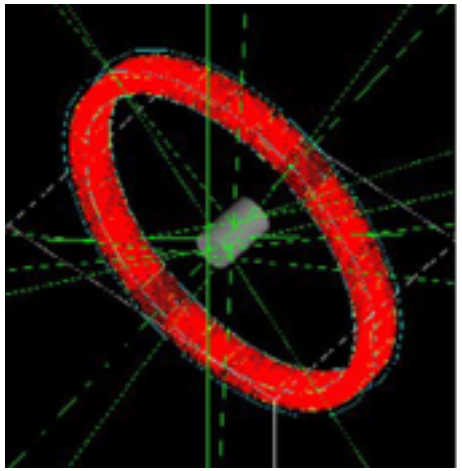

Fig18: run

Scintillation crystals

Crystals are one of the important part of PET camera

Crystals important parameters:

- Materials (GSO, LSO, LYSO, BGO..)
- Shape and geometry

the length of crystals to derivation all information of photons.

If length is less ⟶ we can derivation all information of photons

If length is longer ⟶ we will have some errors like Parallax error(shifting)

- Stopping power

Fig19: Scintillation crystals

Scintillation crystals

choosing crystals completely depend what we want.

Stopping power depend to density.

Fig20: Scintillation crystals

Properties	GSO	BGO	LYSO
Density (g/m^3)	6.7	7.13	7.3
Melting Point (°C)	1900	1050	2047
Index of Refraction	1.87	2.15	1.82
Radiation Length (cm)	1.38	1.10	1.16
Attenuation (cm-1)	0.67	0.96	0.87
Decay Constant (ns)	50	300	50
Light Yield (%) Nal (T1)	35	25	75
Photofraction (%)	25	40	30
Energy Resolution (511 kev,%)	12	16	20
Radioactivity	No	No	Yes

Compare Gate with others

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- Fluka: its good for header part and you should begin from zero to define

- SIMSET, there are some studies that compare these software. But for PET porpuse in most cases Gate won. Gate use less CPU and RAM during simulation and time of simulation in Gate is less than SIMSET, and physist developing and giving new technics to rich best results in Gate one of the popular technics is voxel compressing. SWEDEN university

Nowadays studies on PET by Gate

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Today there are a lot of people that they are researching on PET or SPECT

Purpose: rich real data

decreasing time of simulation by bringing new technics, like voxel compress

developing gate to be able to answer to all questions

```
#=================================================
# VOXELIZED SOURCES
#=================================================
/gate/source/addSource
/gate/source/srcvoxel/attachPhantomTo ncat
/gate/source/srcvoxel/setGPUBufferSize
/gate/source/srcvoxel/setGPUDeviceID
# Read the phantom as usual
/gate/source/srcvoxel/reader/insert
/gate/source/srcvoxel/interfileReader/translator/insert
/gate/source/srcvoxel/interfileReader/rangeTranslator/readTable
/gate/source/srcvoxel/interfileReader/rangeTranslator/describe
/gate/source/srcvoxel/interfileReader/verbose
/gate/source/srcvoxel/interfileReader/readFile
/gate/source/srcvoxel/setType
/gate/source/srcvoxel/gps/particle
/gate/source/srcvoxel/gps/energytype
/gate/source/srcvoxel/gps/monoenergy
/gate/source/srcvoxel/setPosition
/gate/source/srcvoxel/gps/confine
/gate/source/srcvoxel/gps/angtype
```

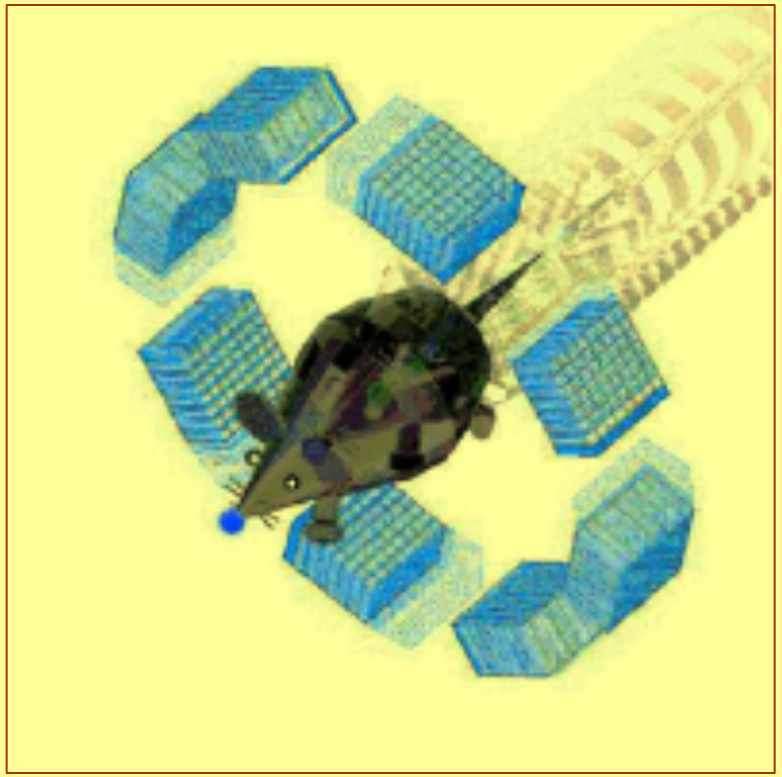
```
#=================================================
# GPU Tracking for optical applications
# V O X E L    S O U R C E
# GPU VERSION
#=================================================
 /gate/source/addSource                    voxel   GPUOpticalVoxel
 /gate/source/voxel/attachPhantomTo                biolumi
 /gate/source/voxel/setGPUBufferSize               5000000
 /gate/source/voxel/setGPUDeviceID                 1
 /gate/source/voxel/energy                         6.0 eV
```

We use Na_{22} because of its half time

more information

- http://www.wiki.opengatecollaboration.org

- Email service like database from all around world



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