GateParamterisedPinholeCollimator class for simulation of preclinical SPECT

May 31, 2022

Contents

1 Aim

This class was developed for simulations of a nanoSPECT/CT (Fig. 1) by Mediso with a pinhole collimator (Fig. 2).

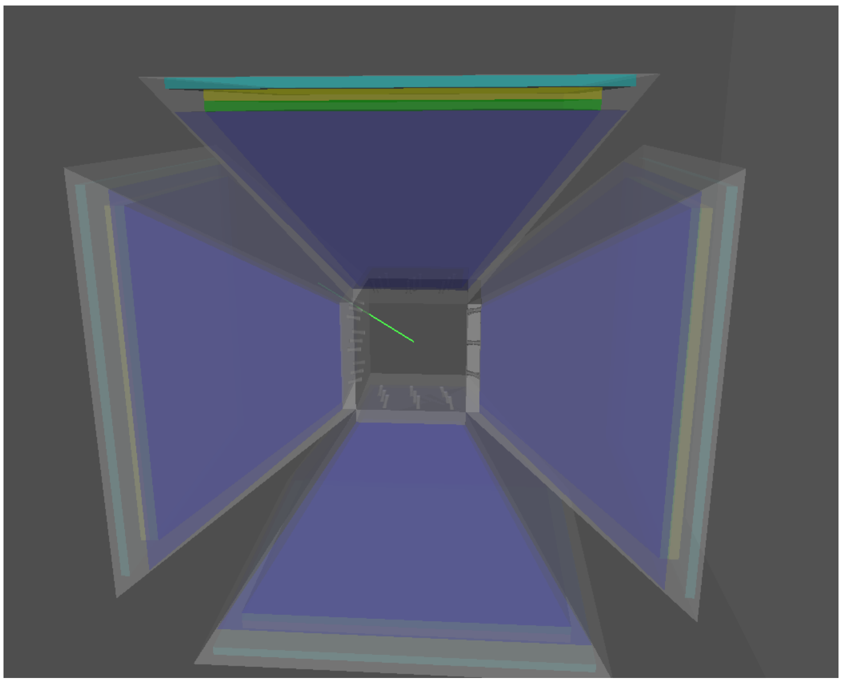


Figure 1: Illustration for simulated nanoSPECT

2 Options and input data

The geometry of pinhole is defined from a G4-pyramid with a subtracted cones in order to have pinholes.

The pyramid is defied with mac options:

```
/gate/colli/geometry/setDimensionX1 80 mm
/gate/colli/geometry/setDimensionY1 84 mm
/gate/colli/geometry/setDimensionX2 80 mm
/gate/colli/geometry/setDimensionY2 84 mm
/gate/colli/geometry/setHeight 10 mm
```

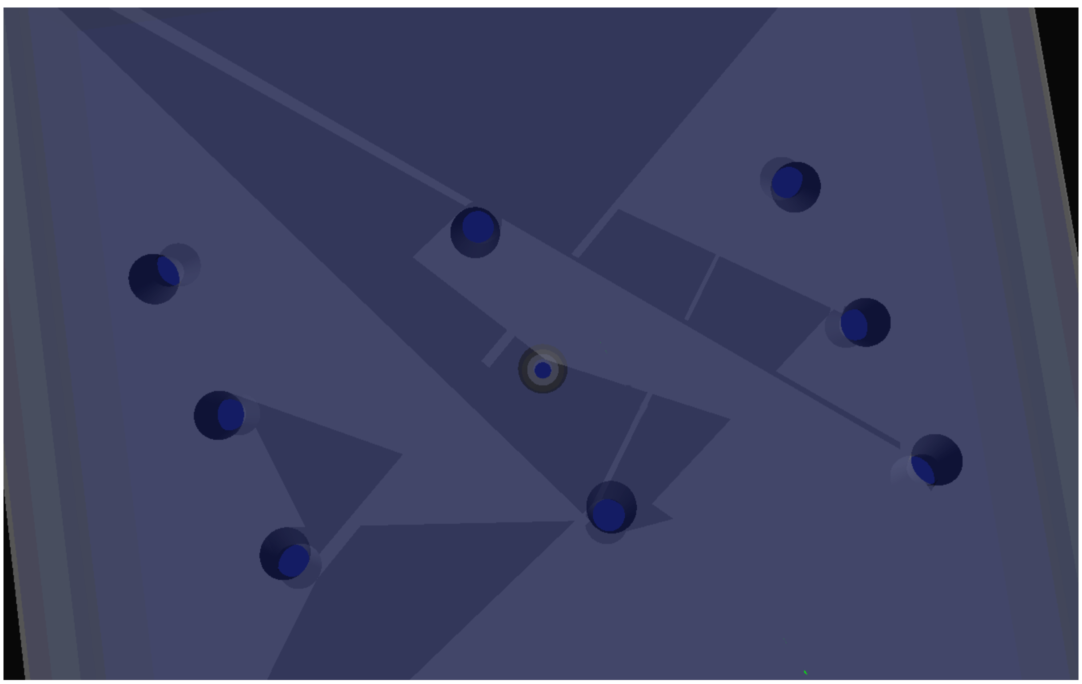


Figure 2: Illustration for pinhole collimator

The collimator rotation radius, i.e. distance from the center of field of view to the pinholes center (see Fig. 3 and Fig, 4) is defined as:

```
/gate/colli/geometry/setRotRadius 45 mm
```

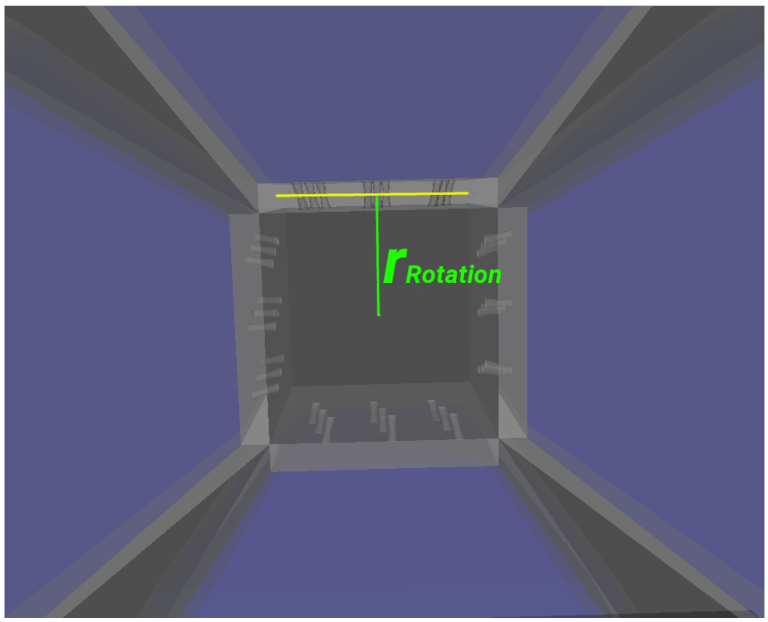


Figure 3: Definition of the rotation radius

The the pinhole geometry is defined with an option file:

```
/gate/colli/geometry/input mac/APT2.pin
```

The stricture of the option file, APT2.pin, is the following (an example could be found in Table 1):

```
Number of pinholes
y z diameter cone_angle focal_point_y focal_point_z
```

In Table 1 one can find a description of APT2 collimator with 9 holes. The diameter of pinholes (at the center) is 2.5 mm, the opening cone angle (α later) is 6.3 degree. The y and z coordinates are the centers of the pinholes. The focal coordinates are illustrated in Fig. 4.

# y	z	dia	cone	focal	point
[APT2]					
9					
-28.5	12.0	2.5	6.3	-18.5	0
-3.5	12.0	2.5	6.3	-3.5	0
21.5	12.0	2.5	6.3	11.5	0
-25.0	0	2.5	6.3	-15	0
0	0	2.5	6.3	0	0
25.0	0	2.5	6.3	15	0
-21.5	-12.0	2.5	6.3	-11.5	0
3.5	-12.0	2.5	6.3	3.5	0
28.5	-12.0	2.5	6.3	18.5	0

Table 1: Example of APT2.pin option file

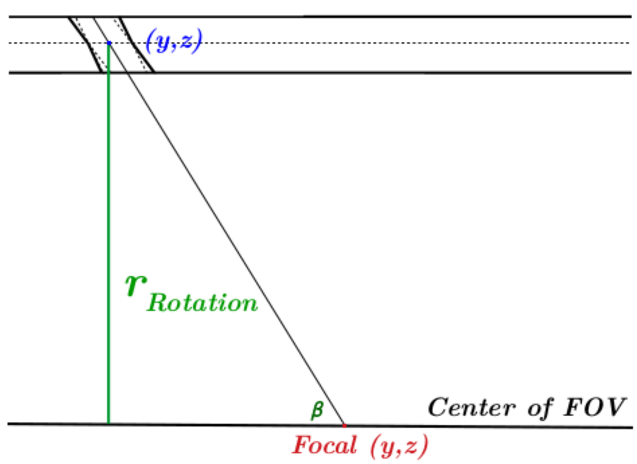


Figure 4: Illustration of parameters defined in APT2.pin option file

3 Pinhole geometry calculations

The result of the following calculations are implemented in GateParametrised-Pinhole class.

3.1 Cone parameters

The names of the variables in the class are the same as in Figure 5. The known parameters are: ***d (= dia)*** - diameter of the pinhole, α = cone opening angle or apex/2, $\beta = \mathbf{90}^\circ - \alpha$, h = half of a thickness of collimator plate.

1. Calculation of l

$$\sin\beta = \frac{h}{l}$$

$$l = \frac{h}{\sin\beta}$$

2. Calculation of k and n

$$\delta = 90^o - (\alpha + \beta)$$

$$\begin{cases} \tan\delta = \frac{1}{\tan(\alpha+\beta)} = \frac{n}{k} \\ \tan(\delta + 2\alpha) = \frac{1}{\tan(\beta-\alpha)} = \frac{n+d}{k} \end{cases}$$

$$\begin{cases} \tan(\alpha+\beta) = \frac{k}{n} \\ \tan(\beta-\alpha) = \frac{k}{n+d} \end{cases}$$

$$\boxed{k = \frac{d \cdot \tan(\beta-\alpha) \cdot \tan(\alpha+\beta)}{\tan(\alpha+\beta) - \tan(\beta-\alpha)}} \tag{1}$$

$$\boxed{n = \frac{k}{\tan(\beta-\alpha)} - d} \tag{2}$$

3. Calculation of a from k and n

$$a = \frac{k}{\cos(\delta+\alpha)} = \frac{k}{\sin\beta}$$

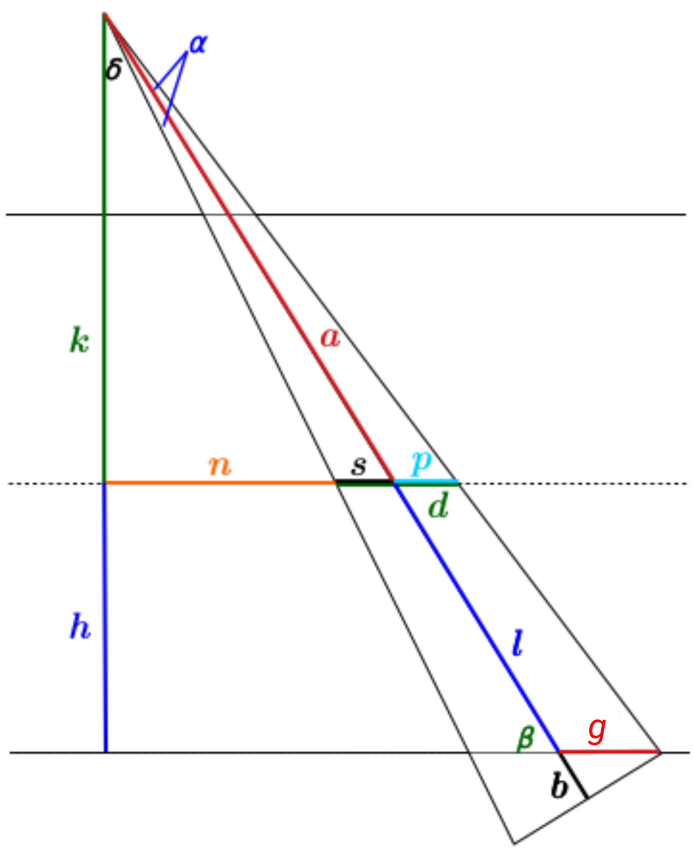


Figure 5: Illustration for pinhole size parameter definitions

$$\boxed{a = \frac{k}{\sin\beta}} \tag{3}$$

4.

$$l = \frac{h}{\cos(\delta+\alpha)} = \frac{h}{\sin\beta}$$

$$\boxed{l = \frac{h}{\sin\beta}} \tag{4}$$

5. Calculation of b

$$\tan(\delta+\alpha) = \frac{1}{\tan\beta} = \frac{n+s}{k}$$

$$\boxed{s = \frac{k}{\tan\beta} - n} \tag{5}$$

$$p = d - s$$

$$\frac{p}{g} = \frac{a}{a+l}$$

$$g = \frac{(d-s)\cdot(a+l)}{a}$$

$$\cos\beta = \frac{b}{g}$$

$$\boxed{b = \frac{(d-s)\cdot(a+l)\cdot\cos\beta}{a}} \tag{6}$$

6. Calculation of *apex* for a chosen direction (x or y)

$$\boxed{apex = a + l + b} \tag{7}$$

7. In more general case:

$$\boxed{apex = \sqrt{apex_x^2 + apex_y^2}} \tag{8}$$

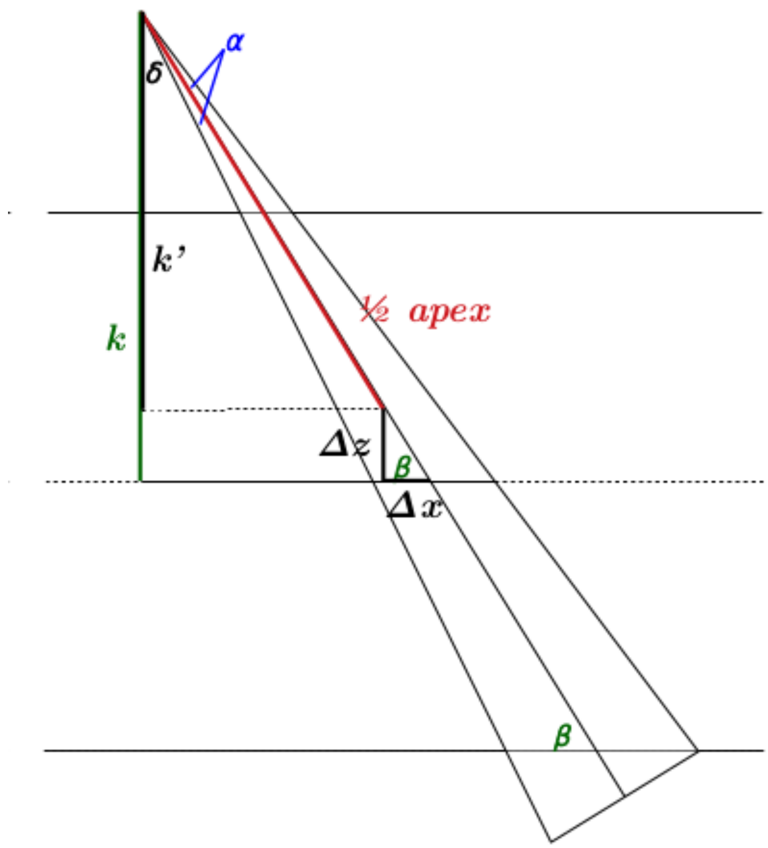


Figure 6: Illustration for pinhole positions definitions

3.2 Cone positions

According to illustration Fig. 6:

1. Calculation of Δz

$$\Delta z = k - k' \tag{9}$$

$$\cos(\delta + \alpha) = \sin\beta = \frac{k'}{apex/2} \tag{10}$$

$$k' = (apex/2) \cdot \sin\beta \tag{11}$$

$$\boxed{\Delta z = k - (apex/2) \cdot \sin\beta} \tag{12}$$

2. Calculation of Δx or Δy in 3D with ϕ as an azimuthal angle:

$$\boxed{\Delta x = \sin\phi \frac{\Delta z}{\tan\beta}} \tag{13}$$

$$\boxed{\Delta y = \cos\phi \frac{\Delta z}{\tan\beta}} \tag{14}$$

4 How to obtain .pin file

One of tricky steps is to obtain the .pin file, i.e. pinhole parameters: positions, diameters, cone opening angles and focal points positions.

4.1 Input from HiSPECT reconstruction software

Here one can find a description of how it was done for one of projects where the simulation of nanoSPECT/CT by Mediso. It is four head camera with several pinhole exchangeable collimators. In our case we were interested in APT1, a collimator for mouse imagning, and APT2, a collimator for rat imagning.

The best way that we found was to search information in integrated reconstruction software of the scanner. In our case it was **HiSPECT**. The pinhole information was stored in (Figure 7)

`Scivis/HiSPECT/SQL/Install/NanoSPECT_Aperture_4det.sql`

In Figure 7, the lines corresponding to APT1 and APT2 apertures are highlighted.

The explanations of corresponding table structures were located in

`Scivis/HiSPECT/SQL/Install/HiSPECT.sql`

and also given in Figure 8.

The pinhole definitions are shown in Figure 9. The most interesting parameters in our case are: yPosition, zPosition, Diameter, ApexAngle, phi and theta.

However, in .pin file one should have focal points positions and not angles phi and theta and, thus, conversion should be done. This is done this way for historical reason: we have in-house reconstruction software where .pin files with the defined structure and parameters are used. In order to have the same parameterization files for simulation and reconstruction, we recalculate the focal position from phi and theta. It is done with a tool `HiSPECTtoGATE` described below.‘

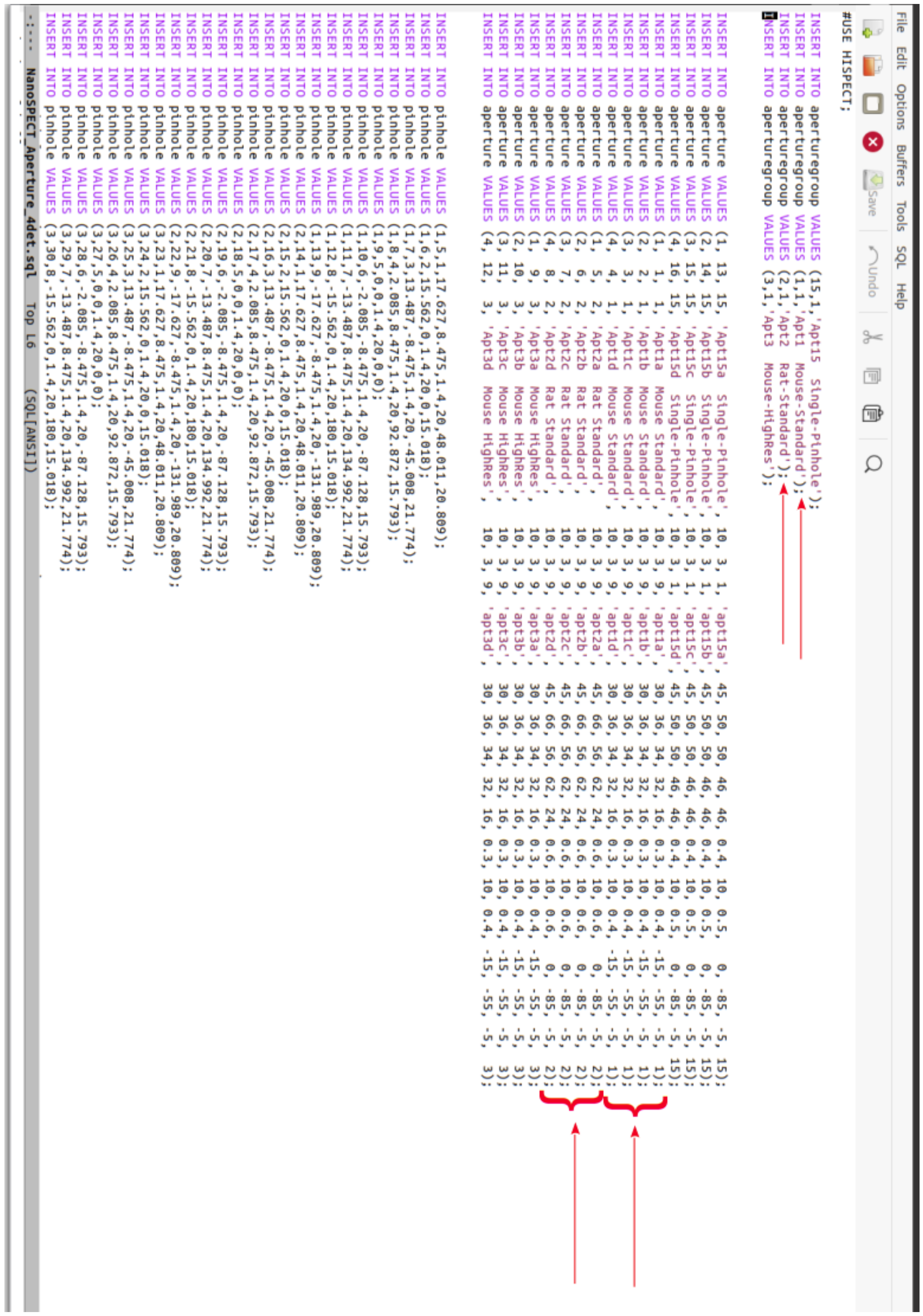
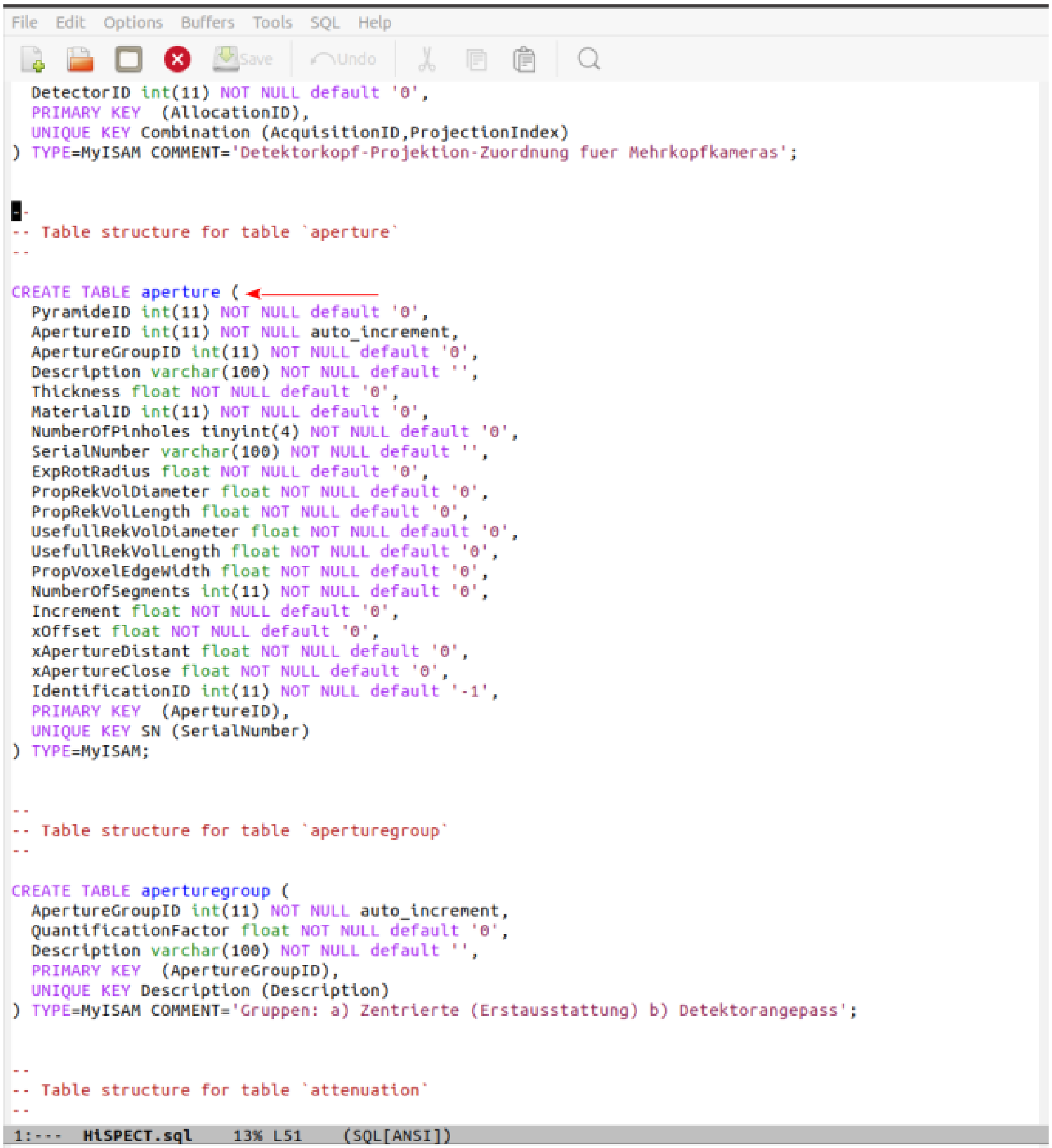


Figure 7: Part of `NanoSPECT_Aperture_4det.sql` file with important lines highlighted




```sql
  DetectorID int(11) NOT NULL default '0',
  PRIMARY KEY  (AllocationID),
  UNIQUE KEY Combination (AcquisitionID,ProjectionIndex)
) TYPE=MyISAM COMMENT='Detektorkopf-Projektion-Zuordnung fuer Mehrkopfkameras';


--
-- Table structure for table `aperture`
--

CREATE TABLE aperture (
  PyramideID int(11) NOT NULL default '0',
  ApertureID int(11) NOT NULL auto_increment,
  ApertureGroupID int(11) NOT NULL default '0',
  Description varchar(100) NOT NULL default '',
  Thickness float NOT NULL default '0',
  MaterialID int(11) NOT NULL default '0',
  NumberOfPinholes tinyint(4) NOT NULL default '0',
  SerialNumber varchar(100) NOT NULL default '',
  ExpRotRadius float NOT NULL default '0',
  PropRekVolDiameter float NOT NULL default '0',
  PropRekVolLength float NOT NULL default '0',
  UsefullRekVolDiameter float NOT NULL default '0',
  UsefullRekVolLength float NOT NULL default '0',
  PropVoxelEdgeWidth float NOT NULL default '0',
  NumberOfSegments int(11) NOT NULL default '0',
  Increment float NOT NULL default '0',
  xOffset float NOT NULL default '0',
  xApertureDistant float NOT NULL default '0',
  xApertureClose float NOT NULL default '0',
  IdentificationID int(11) NOT NULL default '-1',
  PRIMARY KEY  (ApertureID),
  UNIQUE KEY SN (SerialNumber)
) TYPE=MyISAM;


--
-- Table structure for table `aperturegroup`
--

CREATE TABLE aperturegroup (
  ApertureGroupID int(11) NOT NULL auto_increment,
  QuantificationFactor float NOT NULL default '0',
  Description varchar(100) NOT NULL default '',
  PRIMARY KEY  (ApertureGroupID),
  UNIQUE KEY Description (Description)
) TYPE=MyISAM COMMENT='Gruppen: a) Zentrierte (Erstausstattung) b) Detektorangepass';


--
-- Table structure for table `attenuation`
--
```

Figure 8: Part of `HiSPECT.sql` file with important lines highlighted

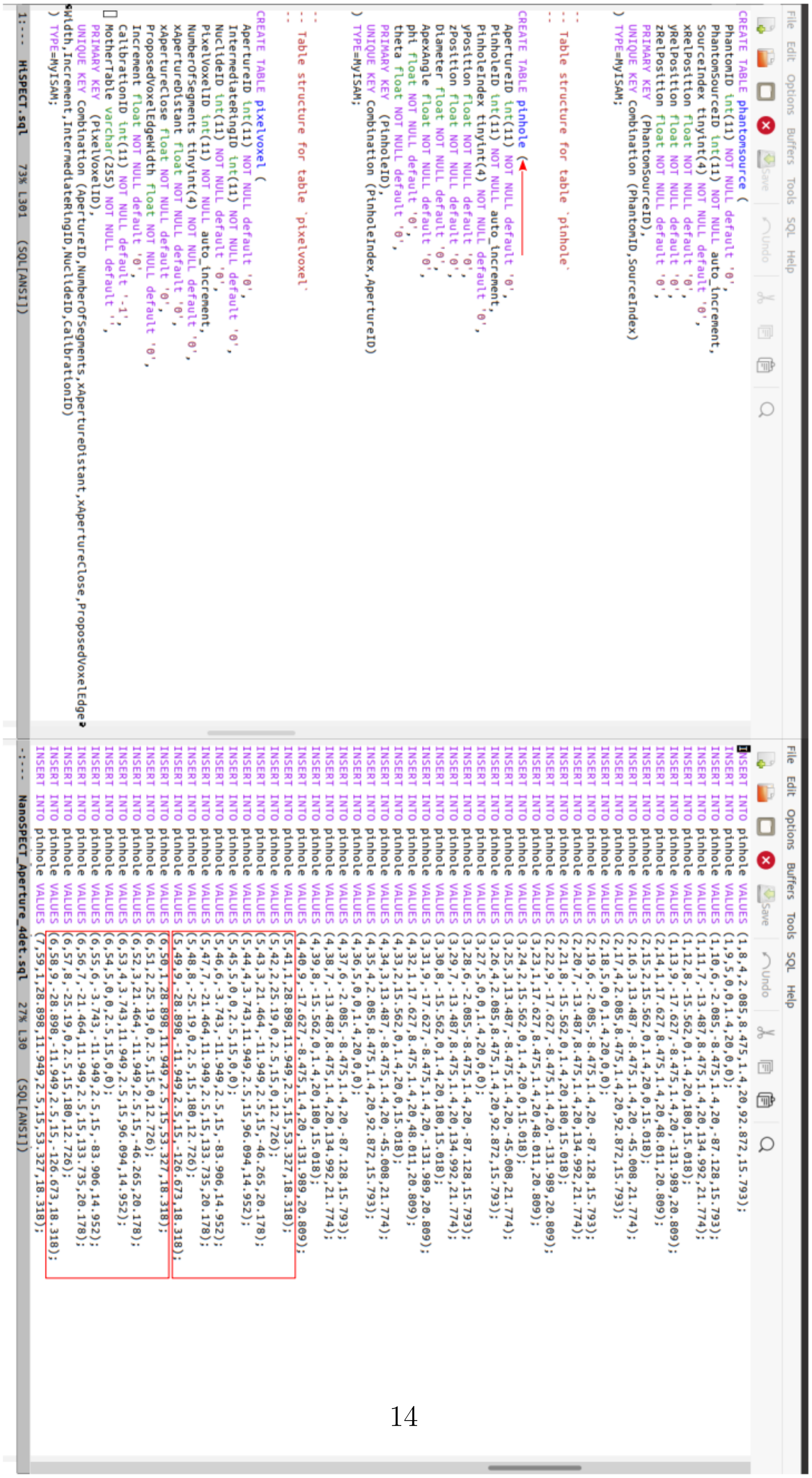


Figure 9: Part of `HiSPECT.sql` and `NanoSPECT_Aperture_4det.sql` file with important lines highlighted

4.2 HiSPECTtoGate tool