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2018 STIR User's and Developer's Meeting

Image reconstruction of GATE SPECT simulation data using STIR

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Date: Thursday, Nov-15-2018
Time: 18:00h – 20:00h
Room: Meeting Room C4.9

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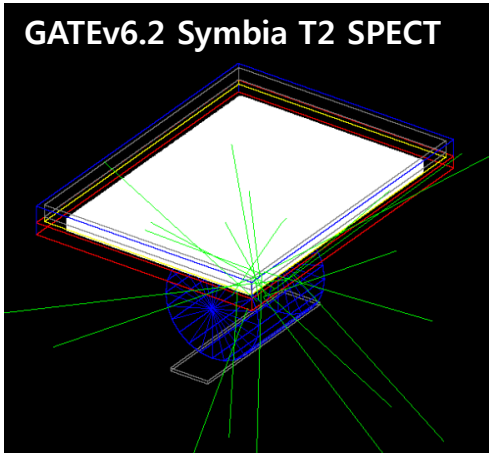
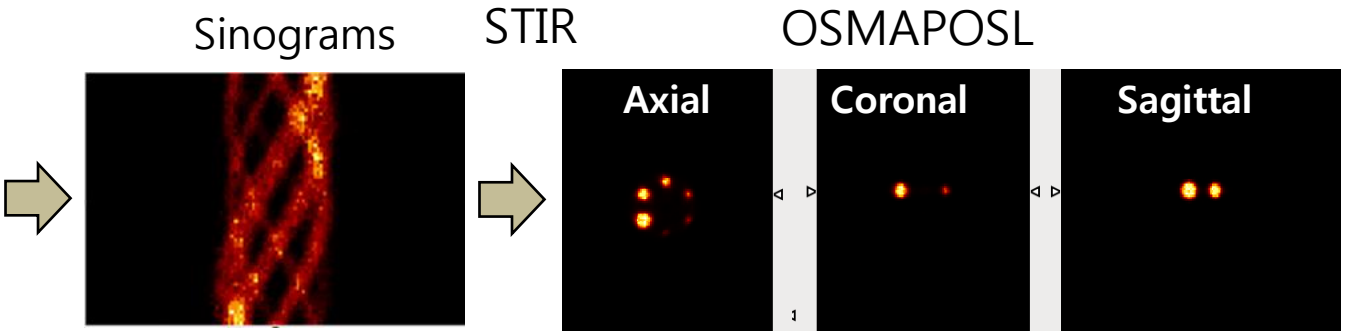
Outline

- GATE SPECT simulation setup
- How to use STIR for SPECT image reconstruction
- STIR SPECT image reconstruction results
  - Clinical SPECT image reconstruction(Symbia T2)
  - Small animal SPECT image reconstruction
- Conclusions and future plan

GATE SPECT simulation





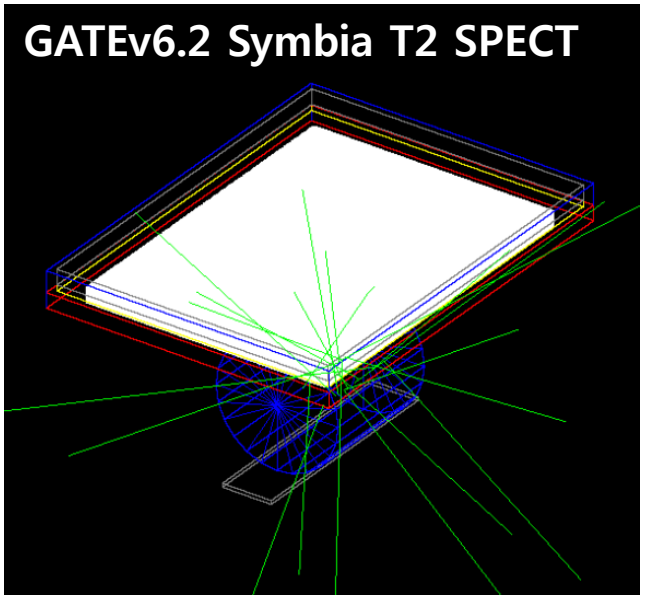
Standard Jaszczak phantom

Unpublished

Clinical SPECT simulation using GATE

<SIEMENS Symbia T2 SPECT/CT>

<GATE Single head SPECT>



Unpublished

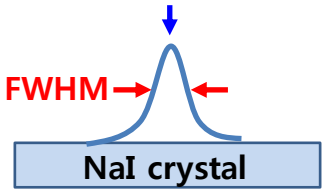
Symbia T2 SPECT specifications (Crystal)

Crystal dimensions (NaI, 59.1×44.5 cm^2)

Detector Shielding

Intrinsic spatial resolution=3.8 mm

Detector Dimensions	Symbia T Series	
FOV	53.3x38.7 cm (21x15.25 in)	
Diagonal FOV	65.9 cm (25.9 in)	
Crystal	**Symbia T Series**	
Size	59.1x44.5 cm (23.25x17.5 in)	
Diagonal	73.9 cm (29.1 in)	
Thickness	9.5 mm (3/8 in) or 15.9 mm (5/8 in)	
Photomultiplier Tubes	**Symbia T Series**	
Total Number	59	
Diameter	53-7.6 cm (3 in) and 6-5.1 cm (2.4-2 in)	
Type	Bialkali high-efficiency box-type dynodes	
Array	Hexagonal	
Detector Shielding	**Symbia T Series**	
Back	9.5 mm (0.375 in)	
Sides	12.7 mm (0.5 in)	
Detector* **	**3/8"**	**5/8"**
Intrinsic Spatial Resolution		
FWHM in CFOV	≤3.8 mm	≤4.5 mm
FWHM in UFOV	≤3.9 mm	≤4.6 mm
FWTM in CFOV	≤7.5 mm	≤8.7 mm
FWTM in UFOV	≤7.7 mm	≤8.9 mm
Intrinsic Energy Resolution		
FWHM in CFOV	≤9.9%	≤9.9%



Symbia T2 SPECT specifications (collimators)

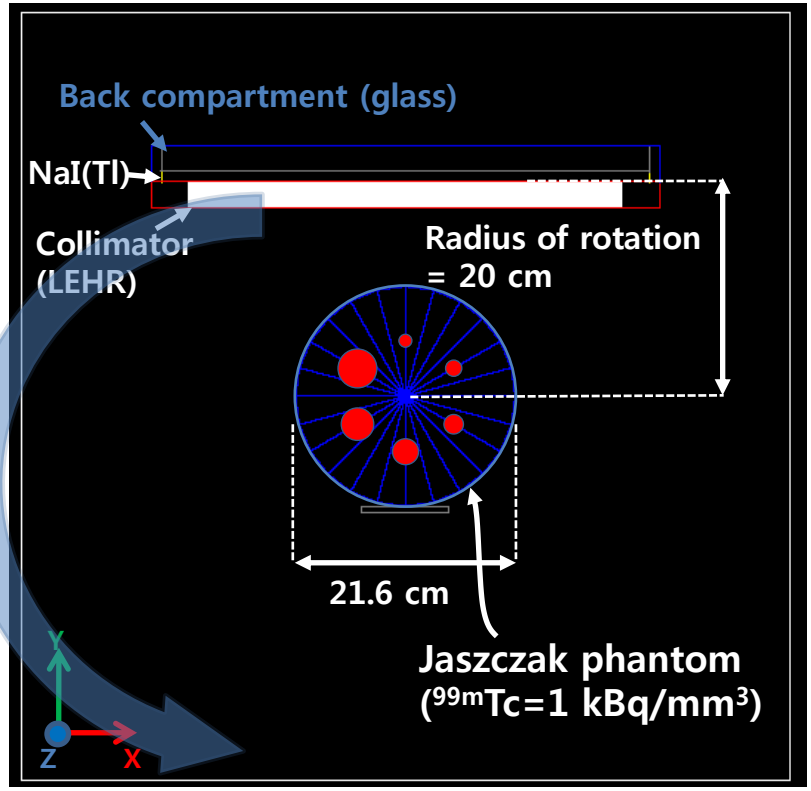
LEHR (Low Energy High Resolution)

Collimators	LEHR	LEAP	LEUHR	LEFB	ME	HE	SMART-ZOOM
	Low Energy High Resolution	Low Energy All Purpose	Low Energy Ultra High Resolution	Low Energy Fan Beam	Medium Energy	High Energy	IQ•SPECT
Isotope	^{99m}Tc	^{99m}Tc	^{99m}Tc	^{99m}Tc	^{67}Ga	^{131}I	^{99m}Tc
Hole Shape	Hex	Hex	Hex	Hex	Hex	Hex	Hex
Number of Holes (x1000)	148	90	146	64	14	8	48
Hole Length	24.05 mm	24.05 mm	35.8 mm	35 mm	40.64 mm	59.7 mm	40.25 mm
Septal Thickness	0.16 mm	0.2 mm	0.13 mm	0.16 mm	1.14 mm	2 mm	0.2-0.4
Hole Diameter Across the Flats	1.11 mm	1.45 mm	1.16 mm	1.53 mm	2.94 mm	4 mm	1.9 mm
Sensitivity at 10 cm*	202 cpm/µCi	330 cpm/µCi	100 cpm/µCi	280 cpm/µCi	275 cpm/µCi	135 cpm/µCi	285 cpm/µCi**
							810 cpm/µCi at 28 cm**
Geometric Resolution at 10 cm	6.4 mm	8.3 mm	4.6 mm	6.3 mm	10.8 mm	13.2 mm	6.95 mm
System Resolution at 10 cm*	7.5 mm	9.4 mm	6.0 mm	7.3 mm	12.5 mm	13.4 mm	7.4 mm***
Septal Penetration	1.5%	1.9%	0.8%	1.0%	1.2%	3.5%	N/A

LEHR Collimator

- **Length = 24.05 mm**
- **Septa = 0.16 mm**
- **Hole = 1.11 mm**

GATEv6.2 SPECT simulation setup

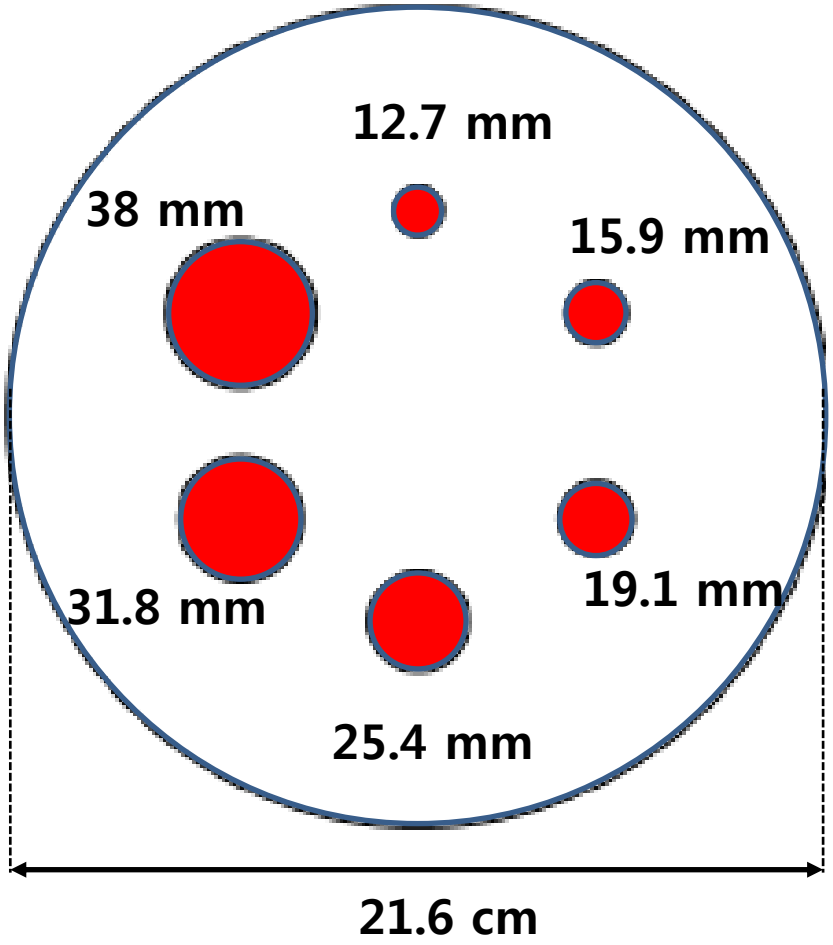


SPECT head rotation = 180°
#Projections =64
Scan time/proj = 1 sec
Rotation speed [degree/sec] = 2.8125

Symbia T2 SPECT specifications

Characteristics	Value
Scintillator	NaI(Tl)
Crystal dimensions [cm]	59.1 x 44.5 x 0.95
#of PMT	59
Diagonal FOV [cm]	63.5
Intrinsic spatial resolution [mm]	3.8 mm
Collimator	**LEHR**
Hole shape	**Hexagonal**
Material	**Lead**
Hole length [mm]	**24.05 mm**
Septal thickness [mm]	**0.16 mm**
Hole diameter accros the flats [mm]	**1.11 mm**
Septal thickness [mm]	**0.16 mm**

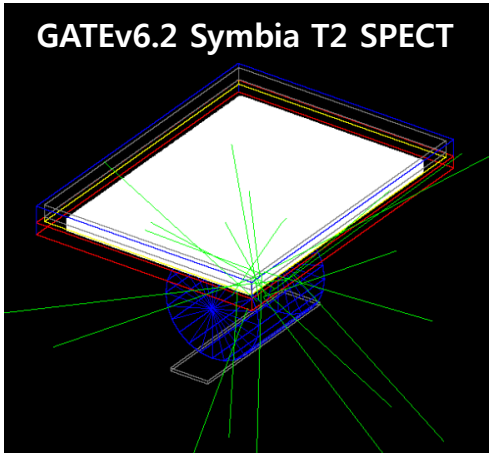
Standard Jaszczak SPECT Phantom



GATE SPECT simulation to STIR OSMAPOSL image reconstruction process

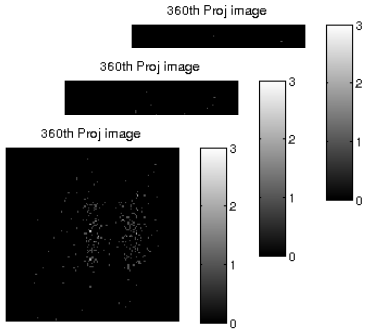
GATE SPECT simulation

#of Projection = **64**



Projection file (interfile)

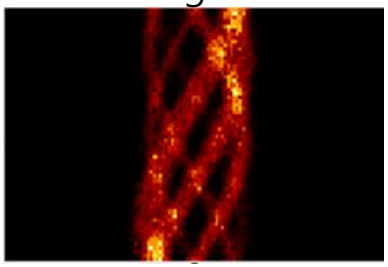
- *.hdr (header)
- ***.sin (Binary image)**



STIR

- OSMAPOSL_osem_SPECT.par
- SPECT_Interfile.hs
- Projection data(*.sin)

Sinogram

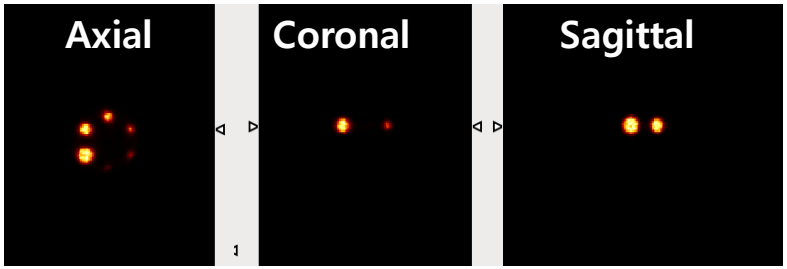


OSEM (Reconstruction)

>**OSMAPOSL** OSMAPOSL_osem_SPECT.par

Reconstructed images

- ✓ ***.v (Recon image)**
- ✓ ***.hv (Header)**
- ✓ *.ahv



Unpublished

STIR OSMAPOSL SPECT Recon method (1)

STIR OSMAPOSL reconstruction command!

> **OSMAPOSL** OSMAPOSO_osem_SPECT.par

OSMAPOSL

OSMAPOSL_osem_SPECT.par

- Recon Parameter file
- Input : *.hs
- Output : *.v, *.hv, *.ahv
- Matrix size of the recon image
- SPECT UB matrix
- PSF type = Geometrical
- **Attenuation type = No**
- **Mask type = No**
- **Keep all views = 0 (default)**
- **#of subset**
- **#of iteration**

SPECT_Interfile.hs

- Projection header file
- **Input : GATE SPECT (*.sin)**
- Set the x,y pixel size [mm], matrix dimensions of the projection file
- **Radius of rotation**
- CW, CCW
- Set the start angle

OSMAPOSL (Ordered Subsets Maximum A Posteriori One Step Late)

OSMAPOSL_osem_SPECT.par

OSMAPOSL

OSMAPOSL_osem_SPECT.par

- Recon Parameter file
- Input : *.hs
- Output : *.v, *.hv, *.ahv
- Matrix size of the recon image
- SPECT UB matrix
- PSF type = Geometrical
- **Attenuation type = No**
- **Mask type = No**
- **Keep all views = 0 (default)**
- **#of subset**
- **#of iteration**

SPECT_Interfile.hs

- Projection header file
- **Input : GATE SPECT (*.sin)**
- Set the x,y pixel size [mm], matrix dimensions of the projection file
- **Radius of rotation**
- CW, CCW
- Set the start angle

OSMAPOSL (Ordered Subsets Maximum A Posteriori One Step Late)

OSMAPOSL_osem_SPECT.par (1)

OSMAPOSL_osem_SPECT.par (reconstruction parameter file)

```
OSMAPOSLParameters :=
  ; sample .par file to use OSEM on SPECT data.
  ; Any of the algorithm parameters illustrated for PET (such as filtering, prior etc)
  ; will work for SPECT as well, as would OSSPS.
  ; The only thing different here is the projector.

  objective function type:= PoissonLogLikelihoodWithLinearModelForMeanAndProjData

  PoissonLogLikelihoodWithLinearModelForMeanAndProjData Parameters:=

    input file := SPECT_Interfile_header_YZ_Jaszczak_HotSphere_1kBqPer1mm3_ProjNum64.hs

    projector pair type := Matrix

      Projector Pair Using Matrix Parameters :=
        Matrix type := SPECT UB

        Projection Matrix By Bin SPECT UB Parameters:=
            ; width of PSF
            maximum number of sigmas:= 2.0
```

Input: header filename

Matrix type which is used for SPECT reconstruction

Continued…

OSMAPOSL_osem_SPECT.par (2)

OSMAPOSL_osem_SPECT.par (reconstruction parameter file)

```
;PSF type of correction { 2D // 3D // Geometrical }
        psf type:= Geometrical
        ; next 2 parameters define the PSF. They are ignored if psf_type is "Geometrical"
        ; These values are mostly dependent on your collimator.
        ; the PSF is modelled as a Gaussian with sigma dependent on the distance from the collimator
        ; sigma_at_depth = collimator_slope * depth_in_cm + collimator sigma 0(cm)
        collimator slope := 0.0163
        collimator sigma 0(cm) := 0.1466

        ;Attenuation correction { Simple // Full // No }
        ;attenuation type := Simple
        attenuation type := No
        ;Values in attenuation map in cm-1
        attenuation map := attMapRec.hv

        ;Mask properties { Cylinder // Attenuation Map // Explicit Mask // No}
        ;mask type := Explicit Mask
        mask type := No
        mask file := mask.hv
```

Attenuation correction

- Att. map must have the same size as the recon image
- (#column, #rows, #slices, voxel dimensions, orientation)
- Unit of voxel : attenuation coefficient [cm^{-1}]

Select the mask type

```
        ; if next variable is set to 0, only a single view is kept in memory
        keep all views in cache:=0
```

0: Only 1 view is saved for each iteration on RAM

1: Save the every view on RAM which resulted in **"out of memory"**

Continued…

OSMAPOSL_osem_SPECT.par (3)

OSMAPOSL_osem_SPECT.par (reconstruction parameter file)

```
End Projection Matrix By Bin SPECT UB Parameters:=

    End Projector Pair Using Matrix Parameters :=

end PoissonLogLikelihoodWithLinearModelForMeanAndProjData Parameters:=

; best to specifiy an initial image (e.g. filled with 1) for sizes
; or see OSMAPOSL_osem_with_interfiltering.par and FBP2D_SPECT.par for some keywords
;initial estimate:= init.hv
output filename prefix :=
OSMAPOSL_SPECT_Subset1_ProjNum64_HotSphere_1kBqPer1mm3_recon

; needs to be a divisor of the number of views
number of subsets:= 1
number of subiterations:= 100
Save estimates at subiteration intervals:= 5

END :=
```

File name of the Recon image

#of subset

#of iteration

Interval of the image save
If 5: Save the reconstructed image every 5 iteration

Unlike the FBP2D, the matrix size of the reconstructed image is automatically determined. Below is an example.

- Input Projection dimensions : x=128, y=128, #Proj = 64,
- Output Recon dimensions : x=129, y=129, z=255

OSMAPOSL_osem_SPECT.par Recon parameter file end!

SPECT_Interfile.hs

OSMAPOSL

OSMAPOSL_osem_SPECT.par

- Recon Parameter file
- Input : *.hs
- Output : *.v, *.hv, *.ahv
- Matrix size of the recon image
- SPECT UB matrix
- PSF type = Geometrical
- **Attenuation type = No**
- **Mask type = No**
- **Keep all views = 0 (default)**
- **#of subset**
- **#of iteration**

SPECT_Interfile.hs

- Projection header file
- **Input : GATE SPECT (*.sin)**
- Set the x,y pixel size [mm], matrix dimensions of the projection file
- **Radius of rotation**
- CW, CCW
- Set the start angle

OSMAPOSL (Ordered Subsets Maximum A Posteriori One Step Late)

SPECT_Interfile.hs (1)

SPECT_Interfile.hs **: Set the parameters regarding the projection input data**

```
!INTERFILE  :=
; This is a sample minimal header for SPECT tomographic data
; The format is as per the 3.3 Interfile standard (aside from time frame info)

!imaging modality := nucmed

; name of file with binary data
name of data file :=
2016_04_21_Symbia_SPECT_R200mm_YZplane_PixelXY_128x128_Pixel3p4765mmx4p6172mm_SpBlur3p8mm_View64per1sec_Acq
64sec_Jaszczak_HotSphere_1kBqPer1mm3_Proj_test03.sin

!version of keys := 3.3
!GENERAL DATA :=
!GENERAL IMAGE DATA :=
!type of data := Tomographic


; optional keywords specifying patient position (currently ignored)
; patient rotation := prone
; patient orientation := feet_in
```

GATEv6.2 SPECT projection output file (Interfile)

- ***.sin (Projection image, binary)**
- ***.hdr (Projection header , ASCII) -> Not used in STIR**

Continued…

SPECT_Interfile.hs (2)

SPECT_Interfile.hs **: Set the parameters regarding the projection input data**

imagedata byte order := LITTLEENDIAN

!SPECT STUDY (General) :=
; specify how the data are stored on disk
; here given as "single-precision float" (you could have "unsigned integer" data instead)
!number format := unsigned integer
!number of bytes per pixel := 2
!number of projections := 64
⟵ Set the data format and the number of projections

; total rotation (or coverage) angle (in degrees)
!extent of rotation := 180 ⟵ Set the total rotation angle [degree]
process status := acquired
!SPECT STUDY (acquired data):=
; rotation info (e.g. clock-wise or counter-clock wise)
!direction of rotation := CW
start angle := 180
⟵ Clockwise

;!direction of rotation := CCW
;start angle := 0
⟵ Counter-Clockwise

; Orbit definition
orbit := Circular
; radius in mm
Radius := 200
⟵ Circular orbit
Radius = 200 mm

; or
; orbit := Non-circular
; give a list of "radii", one for every position
; Radius := {150, 151, 153, ...}

Continued…

SPECT_Interfile.hs (3)

SPECT_Interfile.hs **: Set the parameters regarding the projection input data**

```
; pixel sizes in the acquired data, first in "transverse" direction, then in "axial" direction
!matrix size [1] := 128
!scaling factor (mm/pixel) [1] := 3.4765
!matrix size [2] := 128
!scaling factor (mm/pixel) [2] := 4.6172

; optional keywords specifying frame duration etc
; These are not according to the Interfile 3.3 specification
; Currently only useful in STIR for dynamic applications
; (but a "time frame" is considered to be all projections acquired at the same time)
;number of time frames := 1
;image duration (sec)[1] := 0
;image relative start time (sec)[1] := 0

!END OF INTERFILE :=
```

transvers (**Y-dir**) matrix size, pixel size of the **projection image**

axial (**Z-dir**) matrix size, pixel size of the **projection image**

SPECT_Interfile.hs **header end!**

Run the STIR OSEM SPECT Reconstruction!

STIR OSMAPOSL reconstruction command!

> **OSMAPOSL** OSMAPOSO_osem_SPECT.par

OSMAPOSL

OSMAPOSL_osem_SPECT.par

- Recon Parameter file
- Input : *.hs
- Output : *.v, *.hv, *.ahv
- Matrix size of the recon image
- SPECT UB matrix
- PSF type = Geometrical
- **Attenuation type = No**
- **Mask type = No**
- **Keep all views = 0 (default)**
- **#of subset**
- **#of iteration**

SPECT_Interfile.hs

- Projection header file
- **Input : GATE SPECT (*.sin)**
- Set the x,y pixel size [mm], matrix dimensions of the projection file
- **Radius of rotation**
- CW, CCW
- Set the start angle

OSMAPOSL (Ordered Subsets Maximum A Posteriori One Step Late)

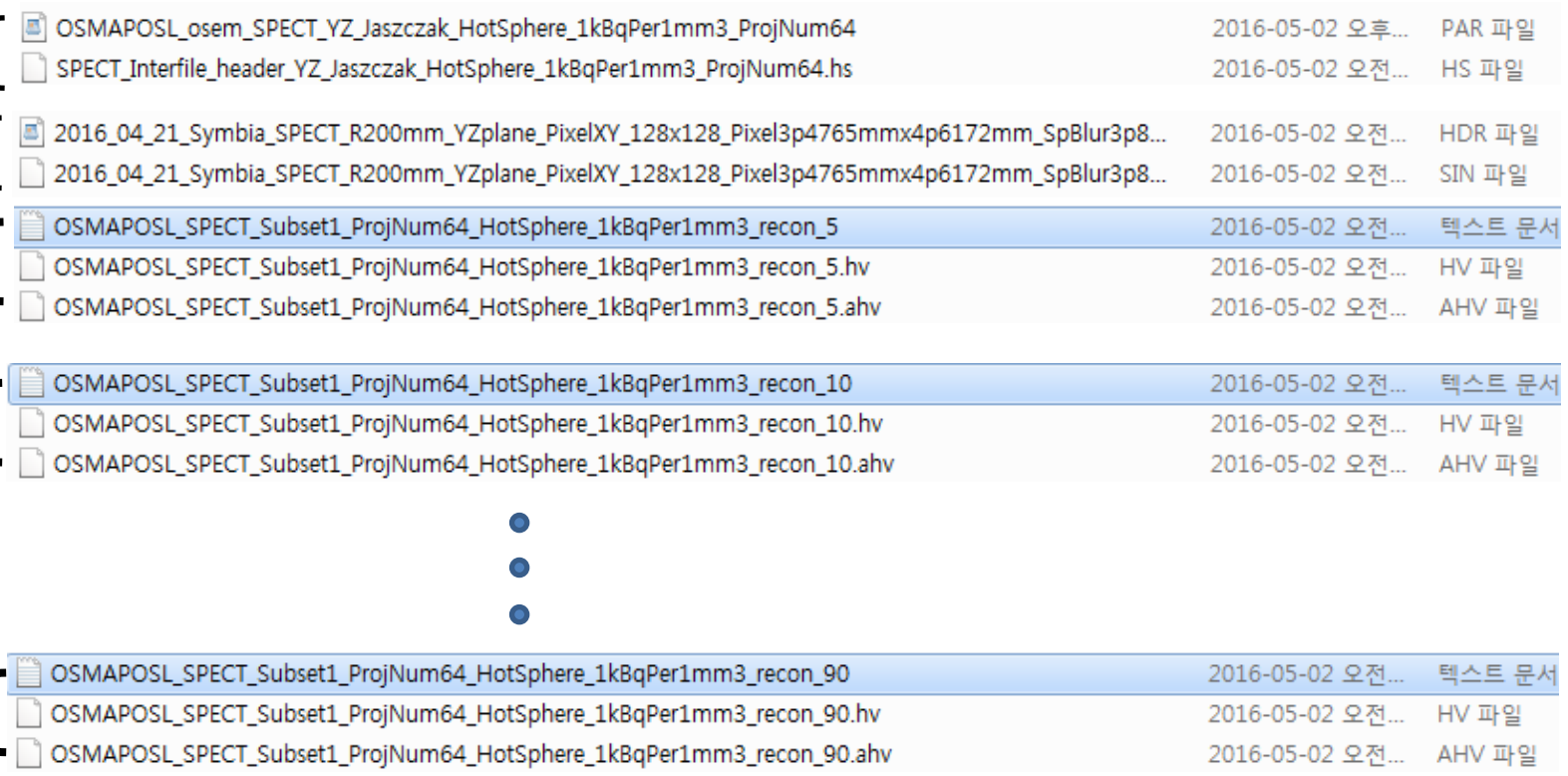
Results of the STIR OSMAPOSL reconstruction

STIR Recon parameter file

- *.par (OSMAPOSL recon parameter)
- *.hs (Projection data interfile header)

Projection interfile

- *.hdr (header)
- *.sin (proj)



***.v (Recon image)**

***.hv (header)**

Reconstructed image header file (*.hv)

Header files (*.hv) of the Recon image(*.v)

```
!INTERFILE  :=
name of data file := OSMAPOSL_SPECT_Subset1_ProjNum64_HotSphere_1kBqPer1mm3_recon_8.v
!GENERAL DATA :=
!GENERAL IMAGE DATA :=
!type of data := PET
imagedata byte order := LITTLEENDIAN
!PET STUDY (General) :=
!PET data type := Image
process status := Reconstructed
!number format := float
!number of bytes per pixel := 4
number of dimensions := 3
matrix axis label [1] := x
!matrix size [1] := 129
scaling factor (mm/pixel) [1] := 3.4765
matrix axis label [2] := y
!matrix size [2] := 129
scaling factor (mm/pixel) [2] := 3.4765
matrix axis label [3] := z
!matrix size [3] := 255
scaling factor (mm/pixel) [3] := 4.6172
first pixel offset (mm) [1] := -222.496
first pixel offset (mm) [2] := -222.496
first pixel offset (mm) [3] := 0
number of time frames := 1
!END OF INTERFILE :=
```

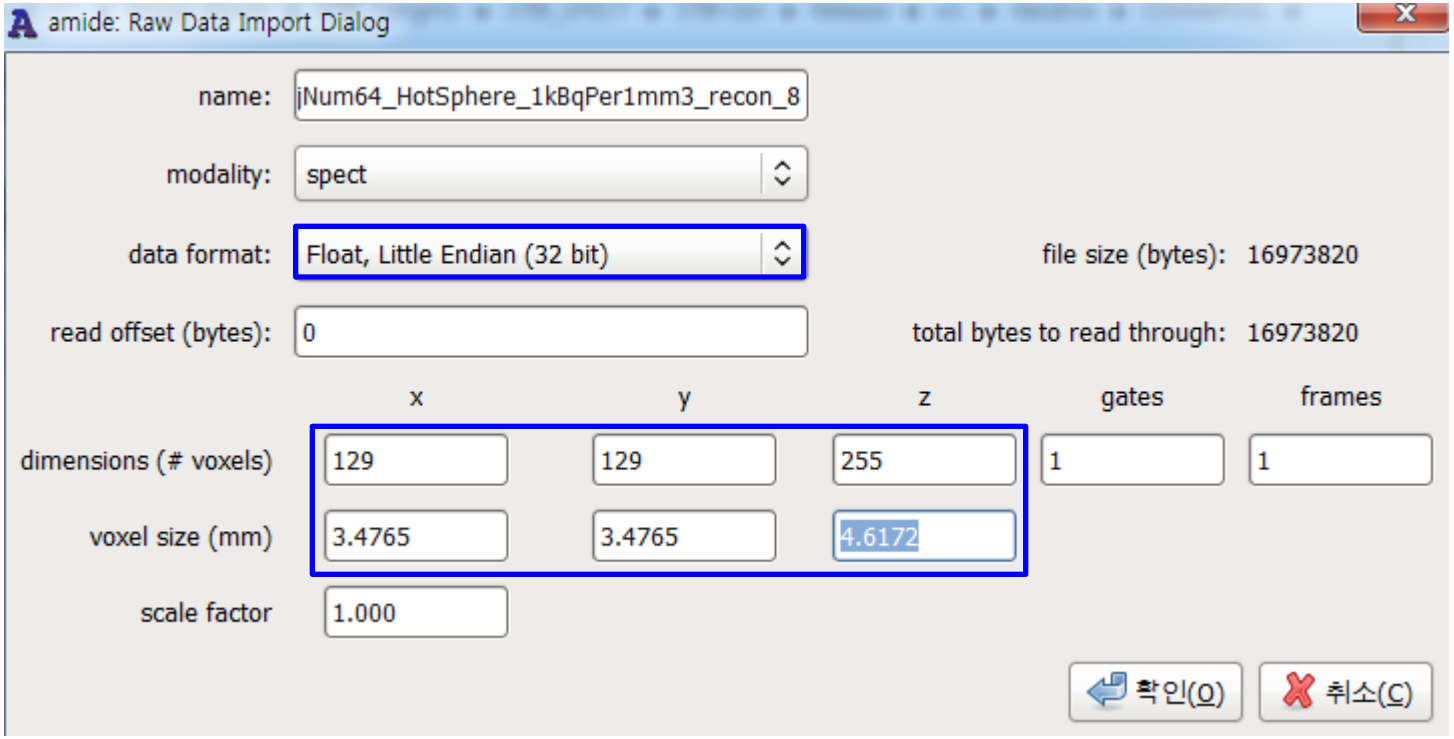
Float, 4 bytes/pixel

Pixel size (x) [mm]

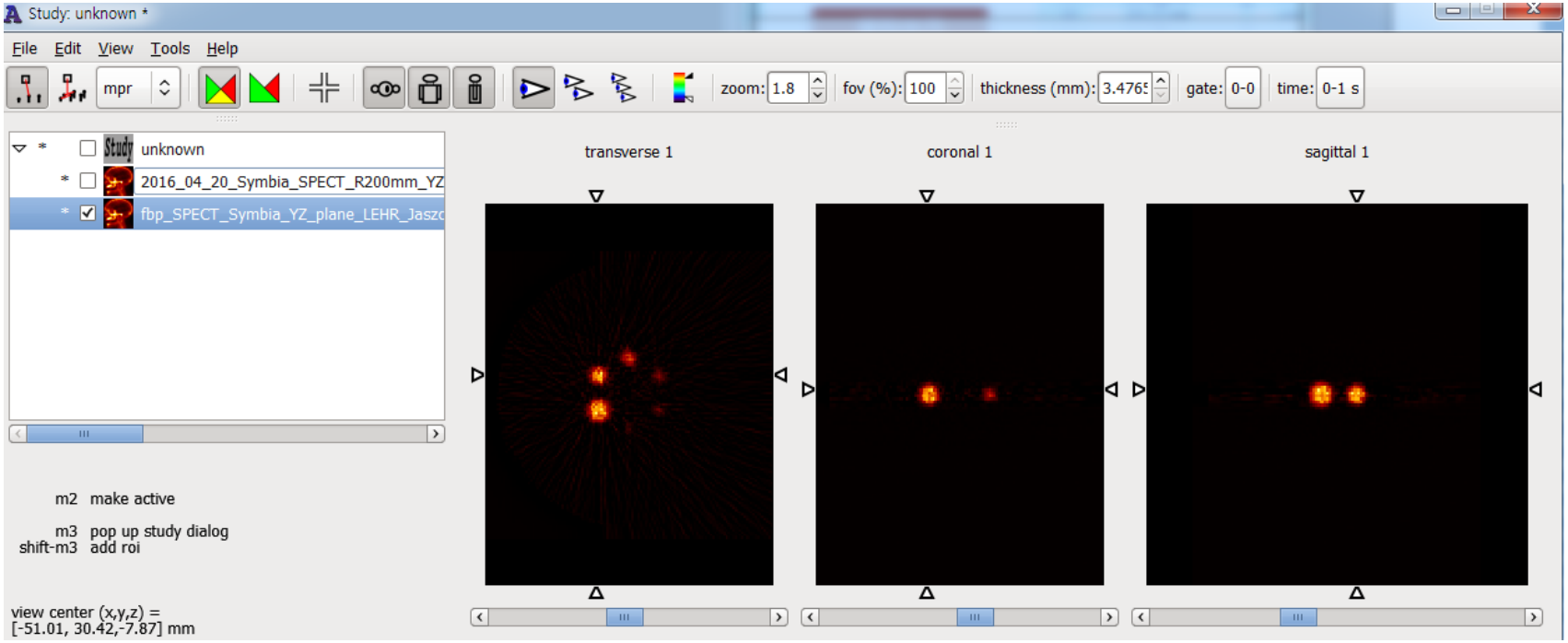
Pixel size (y) [mm]

Pixel size (z) [mm]

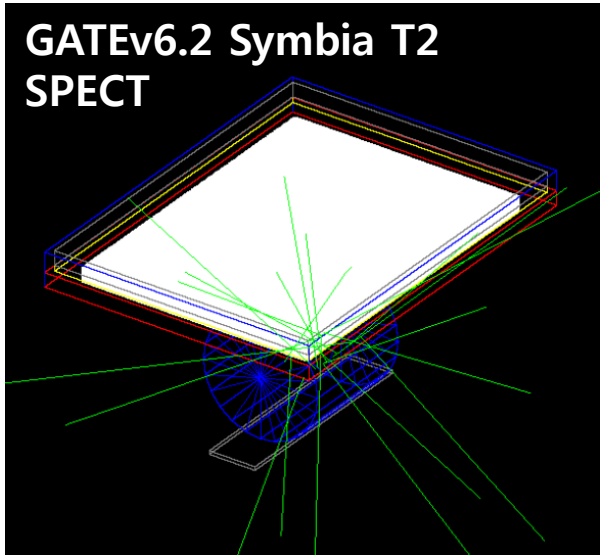
Import the reconstructed image using AMIDE



Import the STIR SPECT Recon image using AMIDE software



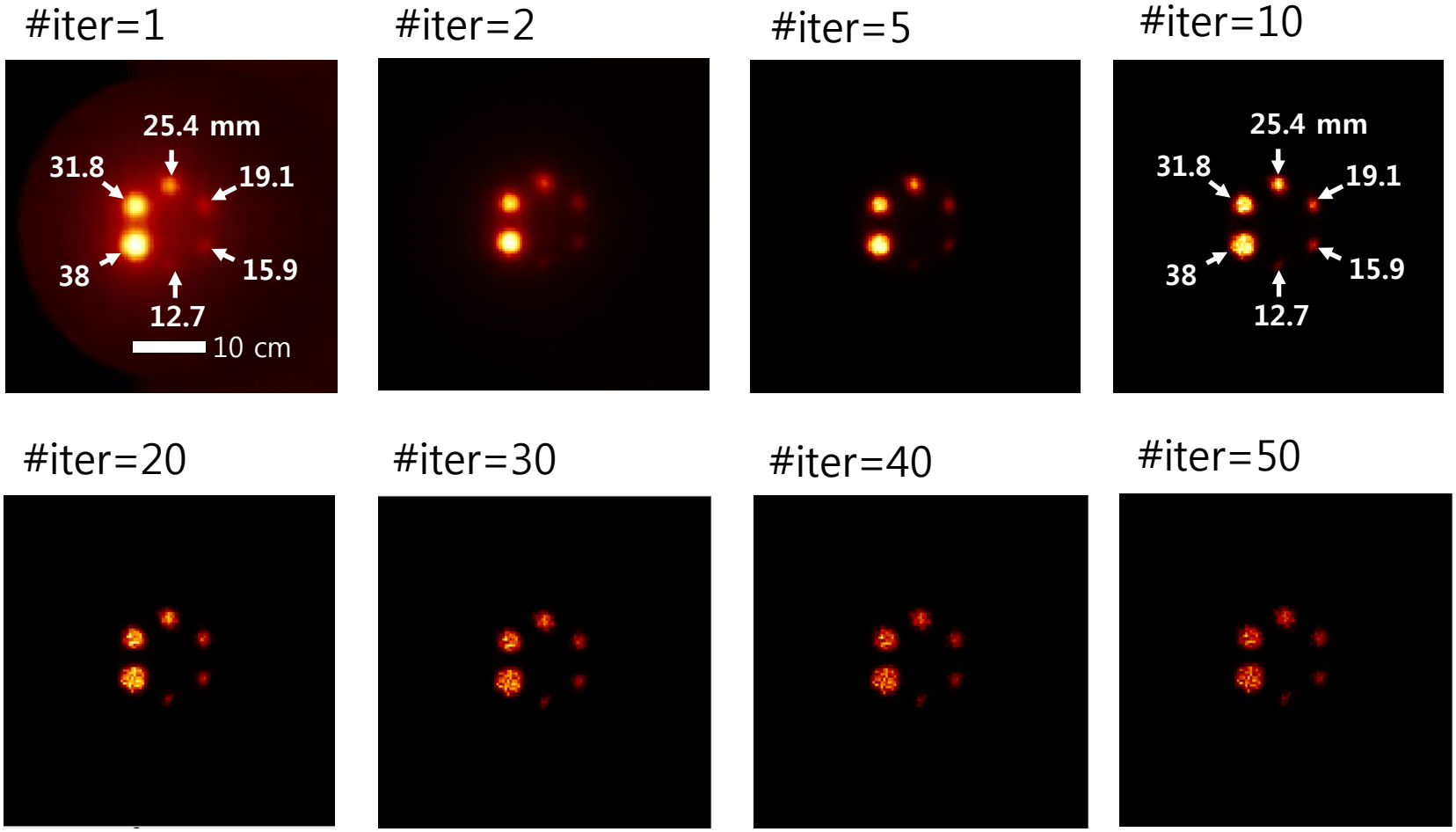
Clinical SPECT simulation using GATE (Siemens, Symbia T2)



#subset = 1

^{99m}Tc concentration
= 1 kBq/mm^3

SPECT image of Standard Jaszczak phantom (Hot)

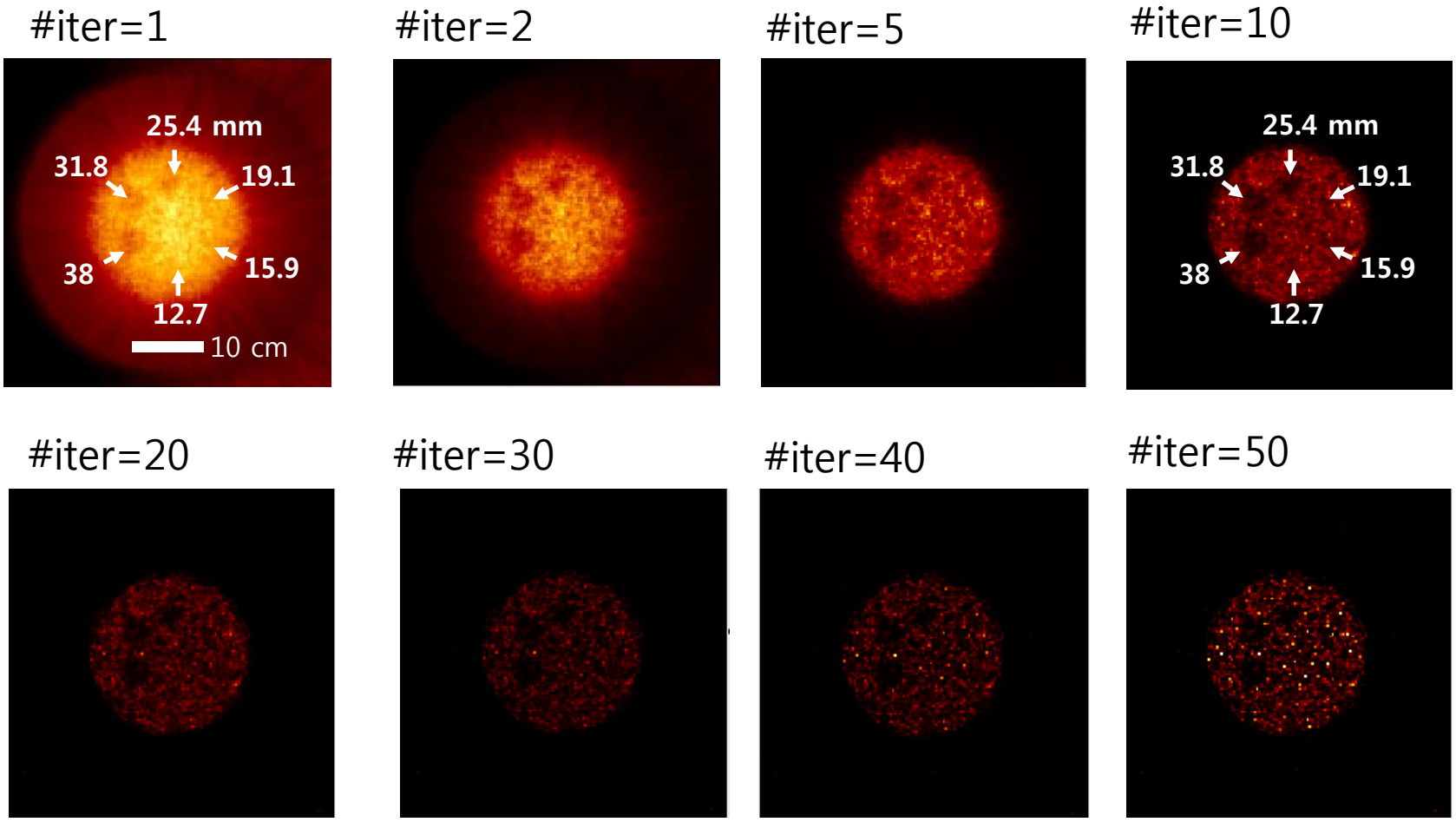


OSMAPOSL (Ordered Subsets Maximum A Posteriori One Step Late) **Unpublished**

#subset = 1

^{99m}Tc concentration
= 27 Bq/mm^3

SPECT image of Standard Jaszczak phantom (Cold)

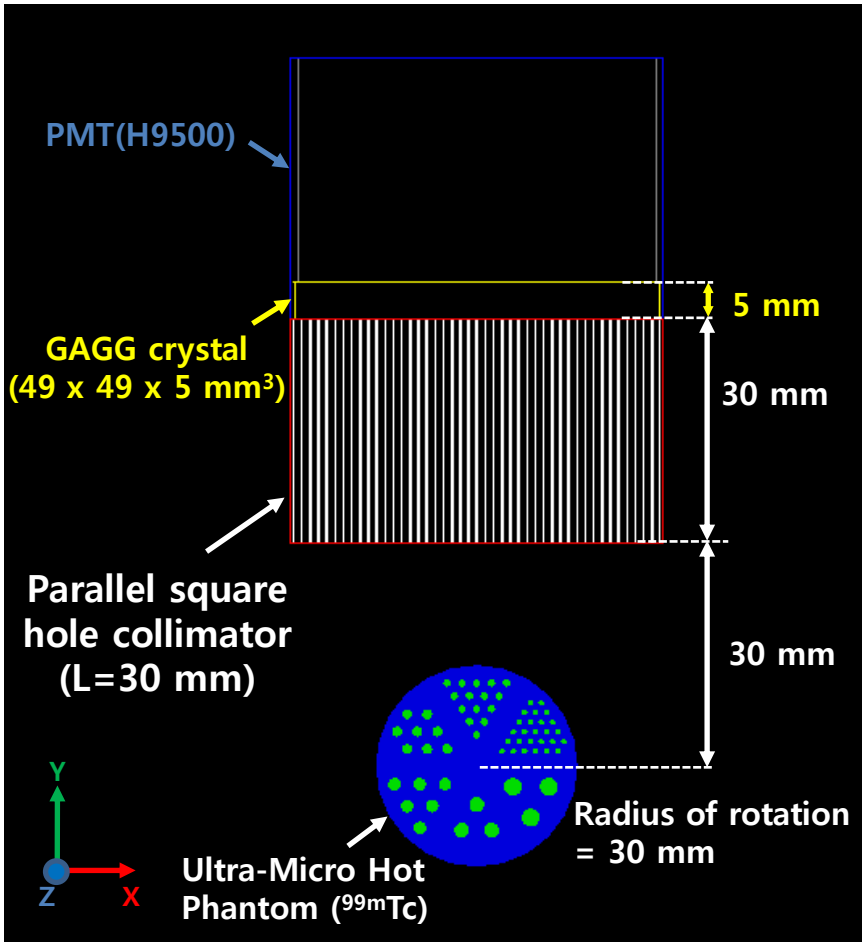


OSMAPOSL (Ordered Subsets Maximum A Posteriori One Step Late) **Unpublished**

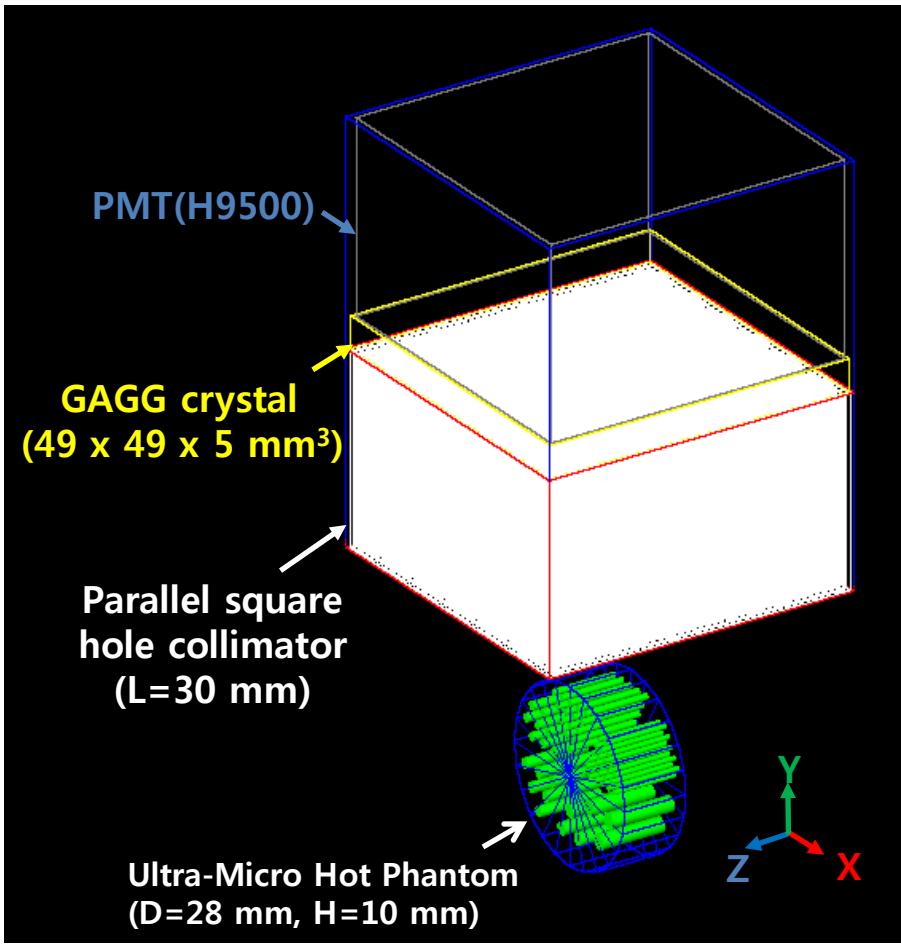
Small animal SPECT simulation using GATE

GATEv6.2 SPECT simulation setup

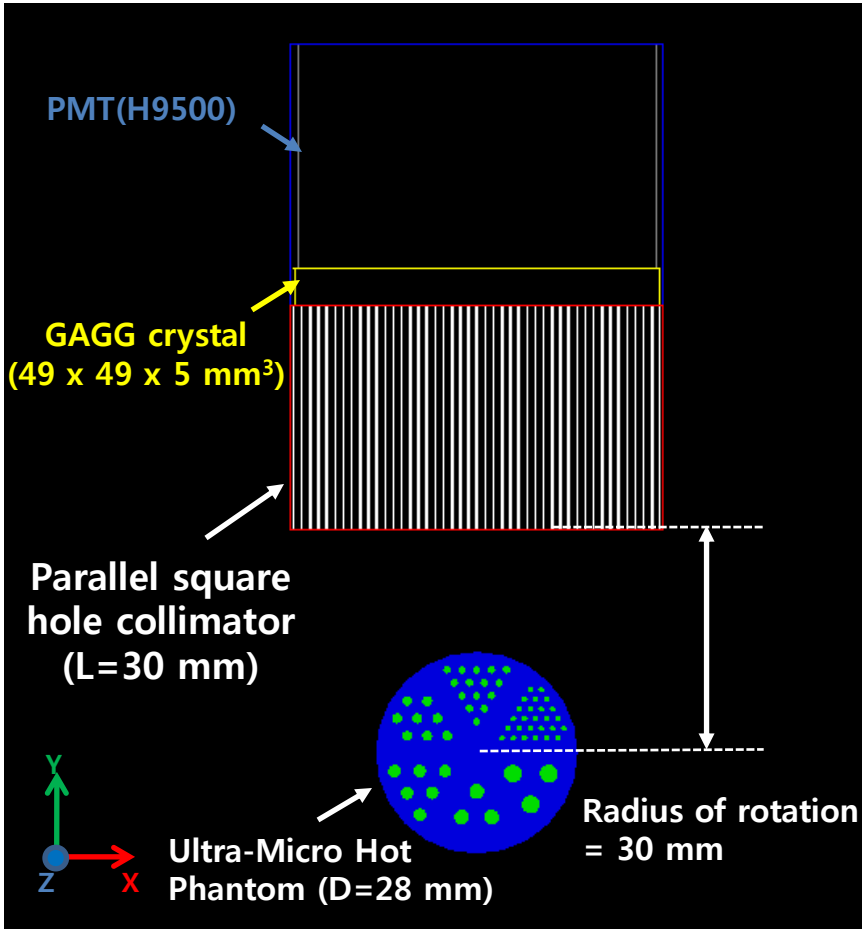
(a) GATE SPECT simulation setup



(b) small animal SPECT (3D view)



GATEv6.2 SPECT simulation setup



SPECT head rotation = 360°
#Projections =128
Scan time/proj = 100 [sec]
Rotation speed [degree/sec] = 0.028125
Total scan time = 128000 [sec]

Small animal SPECT specifications

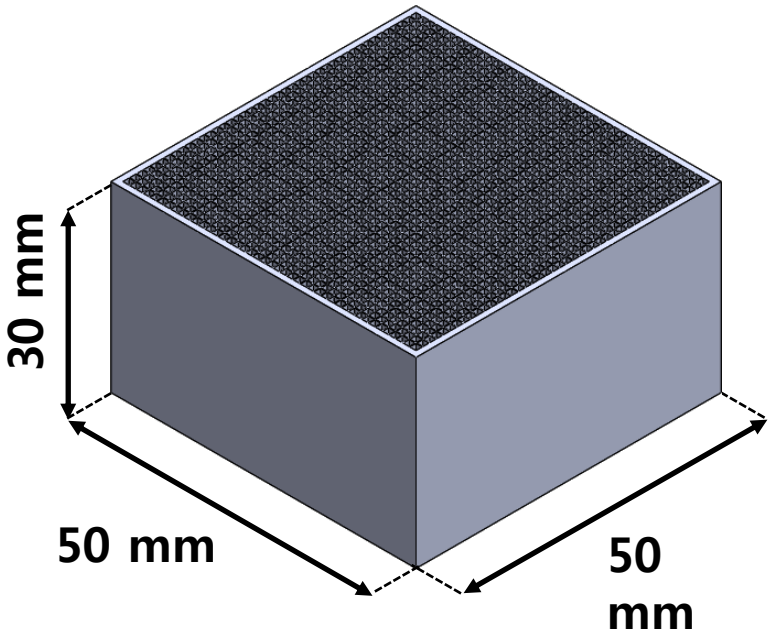
Characteristics	Value
Scintillator	GAGG:Ce
Crystal dimensions [mm]	49 x 49 x 5
#of PMT	1
Diagonal FOV [mm]	69.3
Intrinsic spatial resolution [mm]	1.0 mm
Collimator	**LEHR**
Hole shape	Square
Material	**Tungsten**
Hole length [mm]	**30**
Septa thickness	**0.1**
Hole diameter across the flats	**1.0 mm**

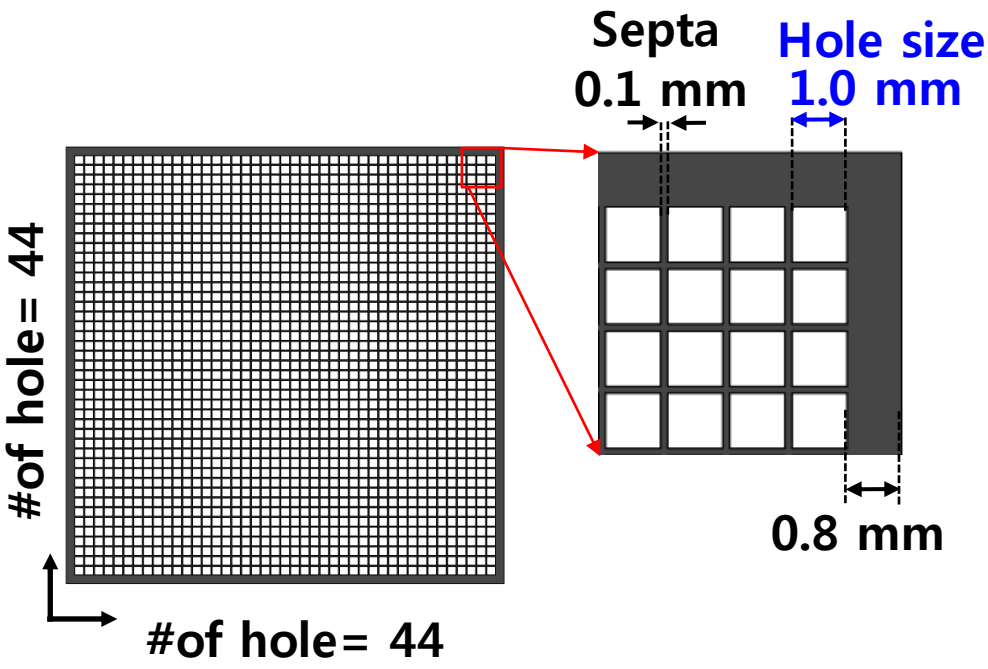
Unpublished

Tungsten square hole parallel collimator

Hole size was changed while the septa was fixed.

<3D view of the collimator>

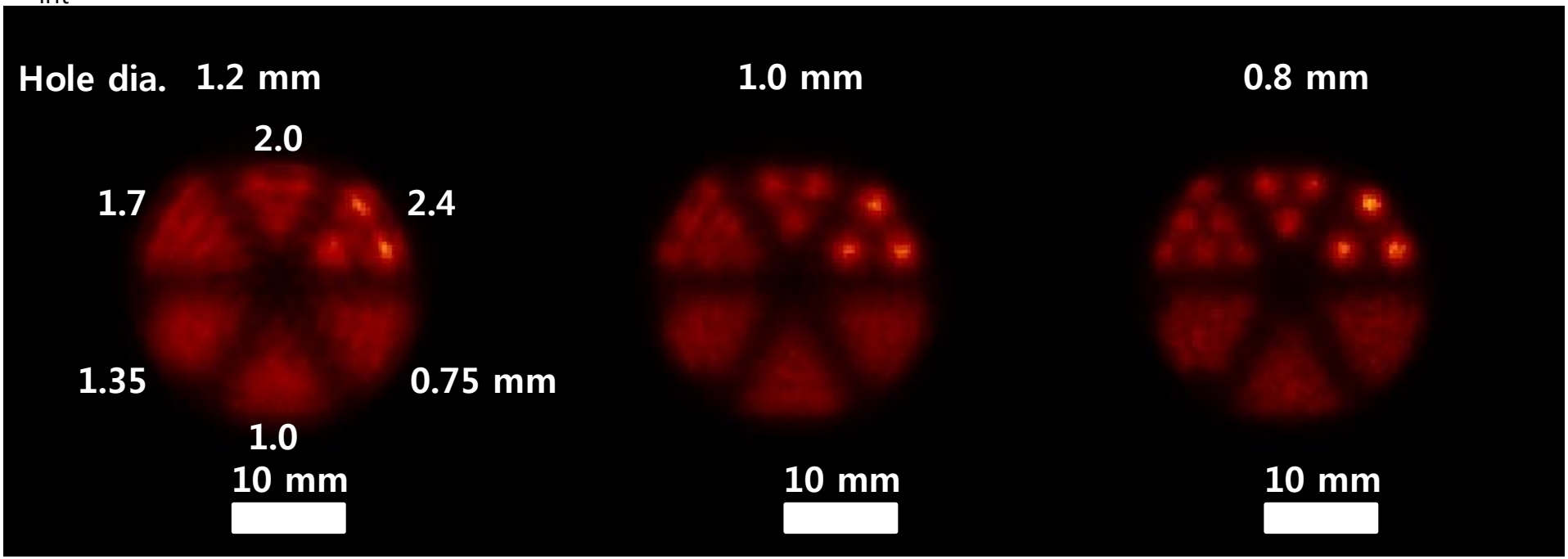




SPECT images of an ultra-micro hot phantom

Tungsten collimator
Septa = 0.1 mm
Length = 30 mm
R_{int} = 1.0 mm

Energy range = 140 keV±10%(126~154 keV)



OSMAPOSL (Ordered Subsets Maximum A Posteriori One Step Late): STIR software

^{99m}Tc activity = 300 [kBq/mL]

Unpublished

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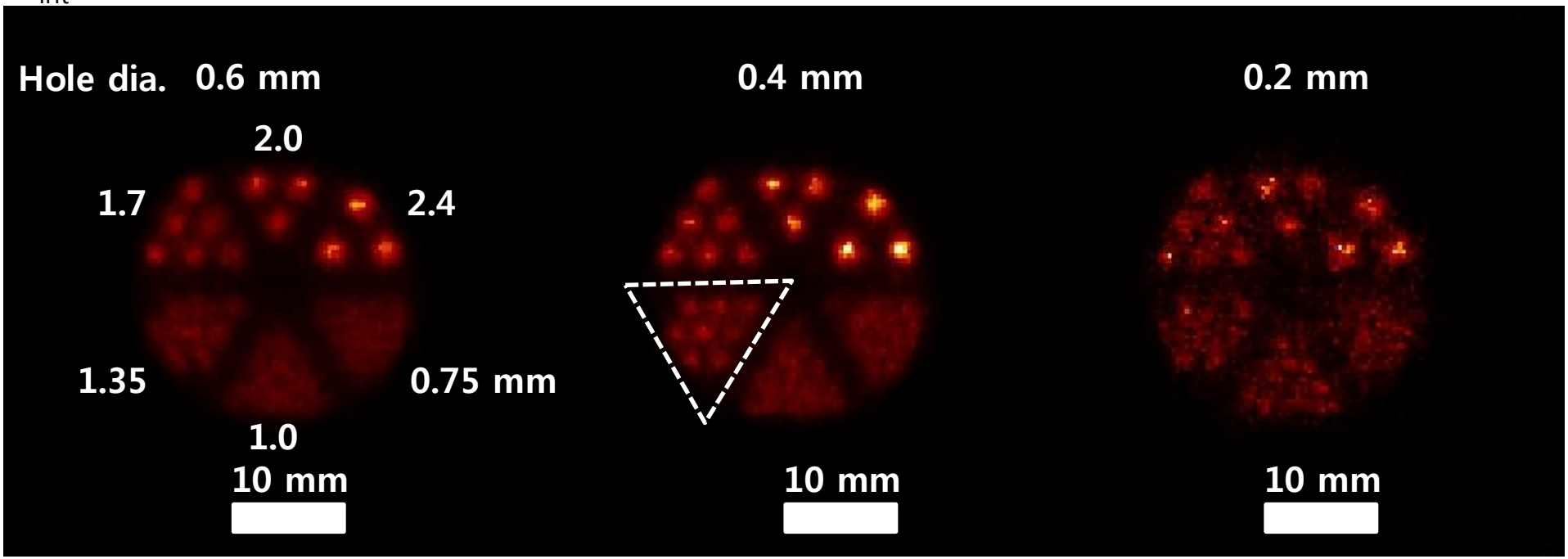
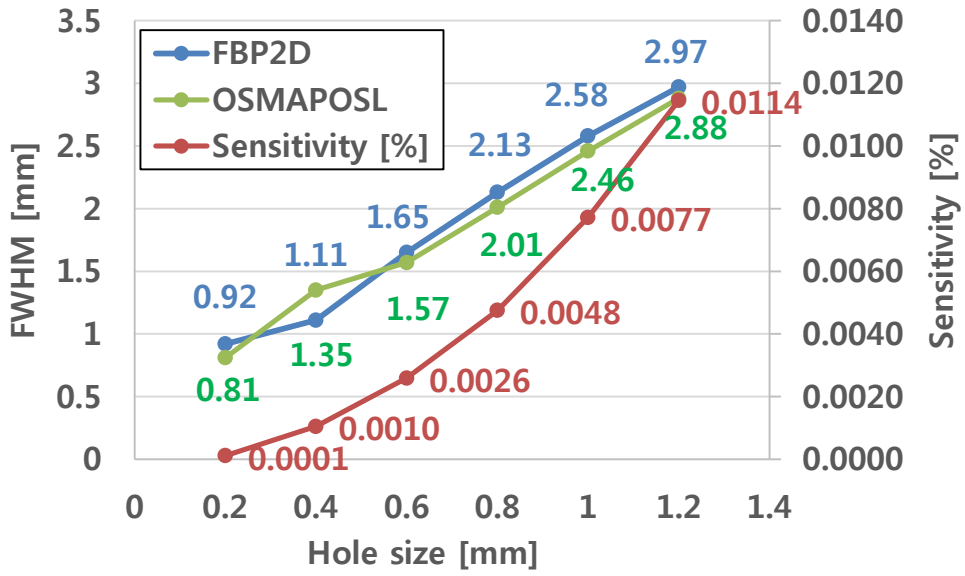


OSMAPOSL (Ordered Subsets Maximum A Posteriori One Step Late): STIR software

^{99m}Tc activity = 300 [kBq/mL]

Unpublished

Spatial resolution and sensitivity depending on the hole size



Conclusions

- **GATE SPECT simulation data** could be reconstructed with **STIR 3.0** using "**SPECT UB projector**".
- The current STIR can't support **pinhole** or **multi-pinhole** SPECT image reconstruction. (**Only parallel collimator is possible**)
- The combination of GATE and STIR has the potential for the development of a custom-made small animal SPECT system

SPECT UB (University of Barcelona) projection
Integration of advanced 3D SPECT modeling into the open-source STIR framework(2013_Medical_Physics)

Thank you for you kind attention.

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