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2018 STIR User's and Developer's Meeting

Image reconstruction of GATE SPECT simulation data using STIR

Han Gyu Kang[1], Hideaki Tashima[1], Seong Jong Hong[2,3], and **Taiga Yamaya**[1]

1. National Institute of Radiological Sciences (NIRS) in National Institutes for Quantum and Radiological Science and Technology (QST), Japan
2. Dept. of Radiological Science, Eulji Univ., Korea
3. Dept. of Senior Healthcare, Eulji Univ., Korea

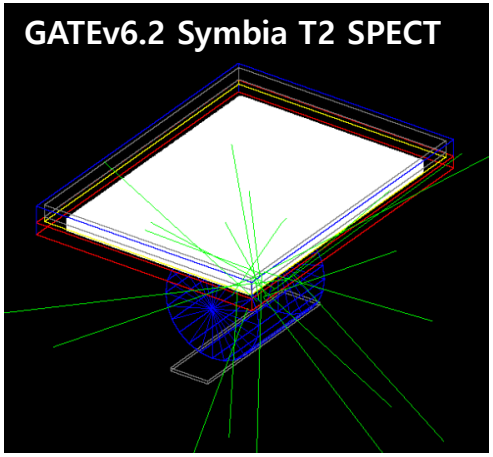
Date: Thursday, Nov-15-2018
Time: 18:00h – 20:00h
Room: Meeting Room C4.9

hangyookang@gmail.com
kang.hangyu@qst.go.jp

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

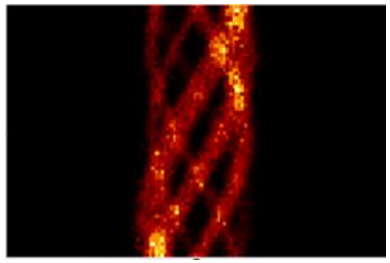
GATE SPECT simulation

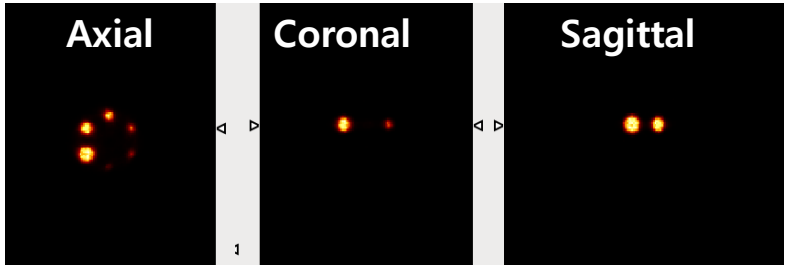


Sinograms

STIR

OSMAPOSL





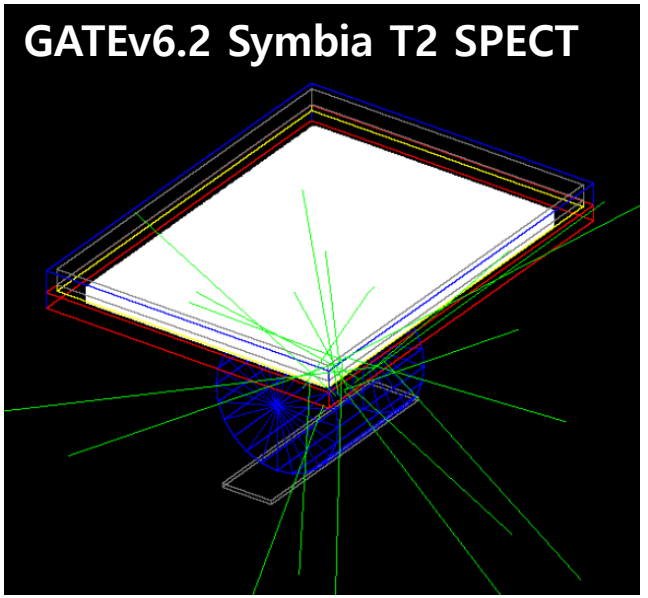
Standard Jaszczak phantom

Unpublished

Clinical SPECT simulation using GATE

<SIEMENS Symbia T2 SPECT/CT>

<GATE Single head SPECT>



Unpublished

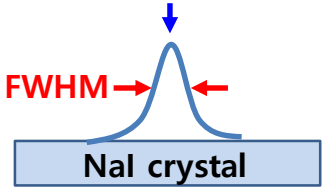
Symbia T2 SPECT specifications (Crystal)

Crystal dimensions (NaI, 59.1×44.5 cm²)

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)

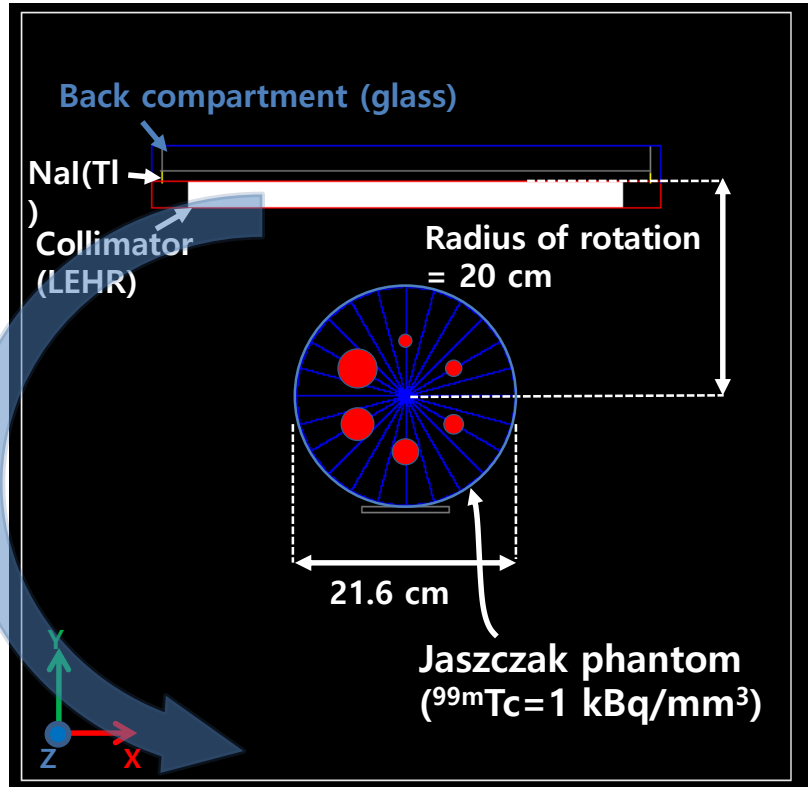
LEHR (Low Energy High Resolution)

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

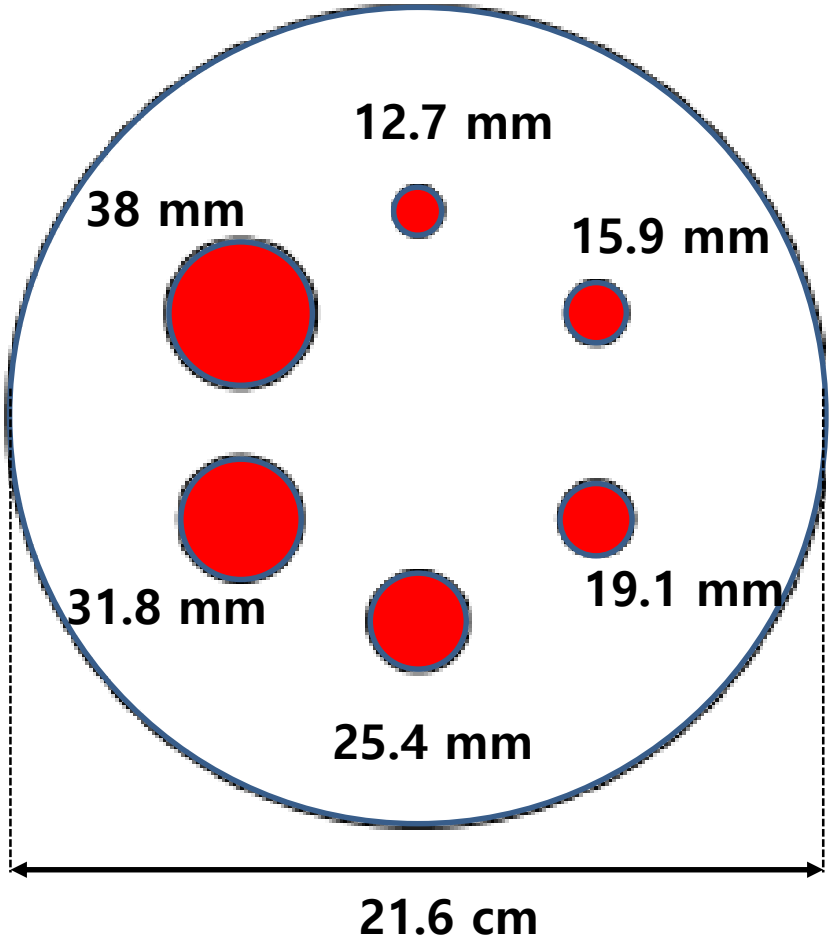


SPECT head rotation = 180°
#Projections =64
Scan time/proj = 1 sec
Rotation speed [degree/sec] = 2.8125

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**

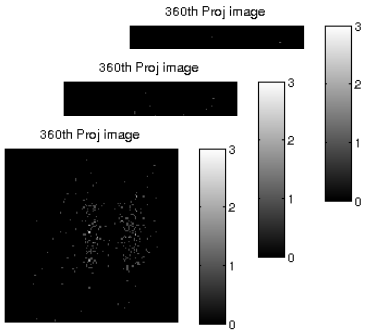
Standard Jaszczak SPECT Phantom

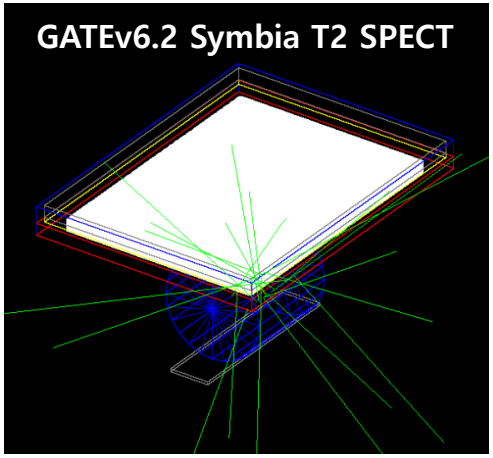


GATE SPECT simulation to STIR OSMAPOSL image reconstruction process

GATE SPECT simulation

#of Projection = **64**





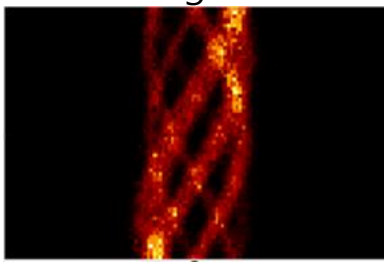
Projection file (interfile)

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

STIR

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

Sinogram

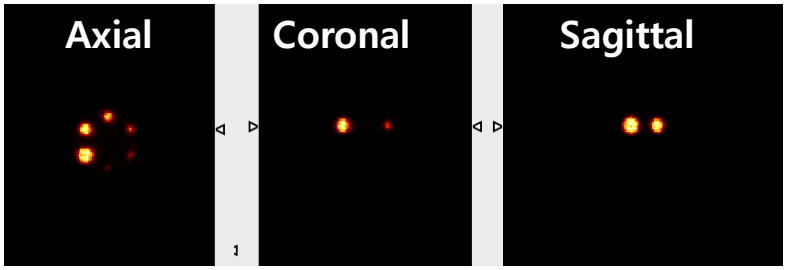


OSEM (Reconstruction)

>**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

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

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

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**

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)

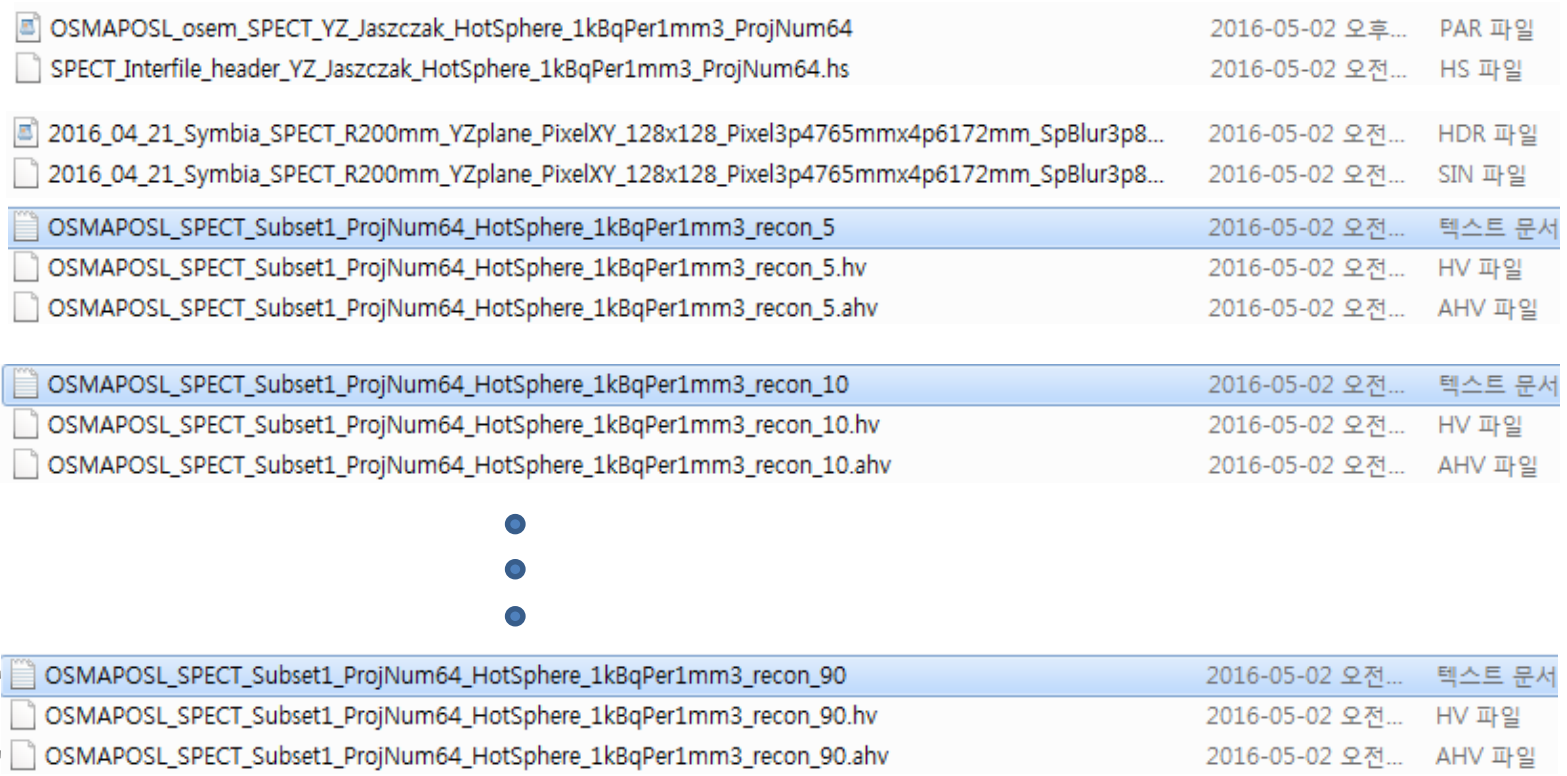
Results of the STIR OSMAPOSL reconstruction

STIR Recon parameter file

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

Projection interfile

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



***.v (Recon image)**

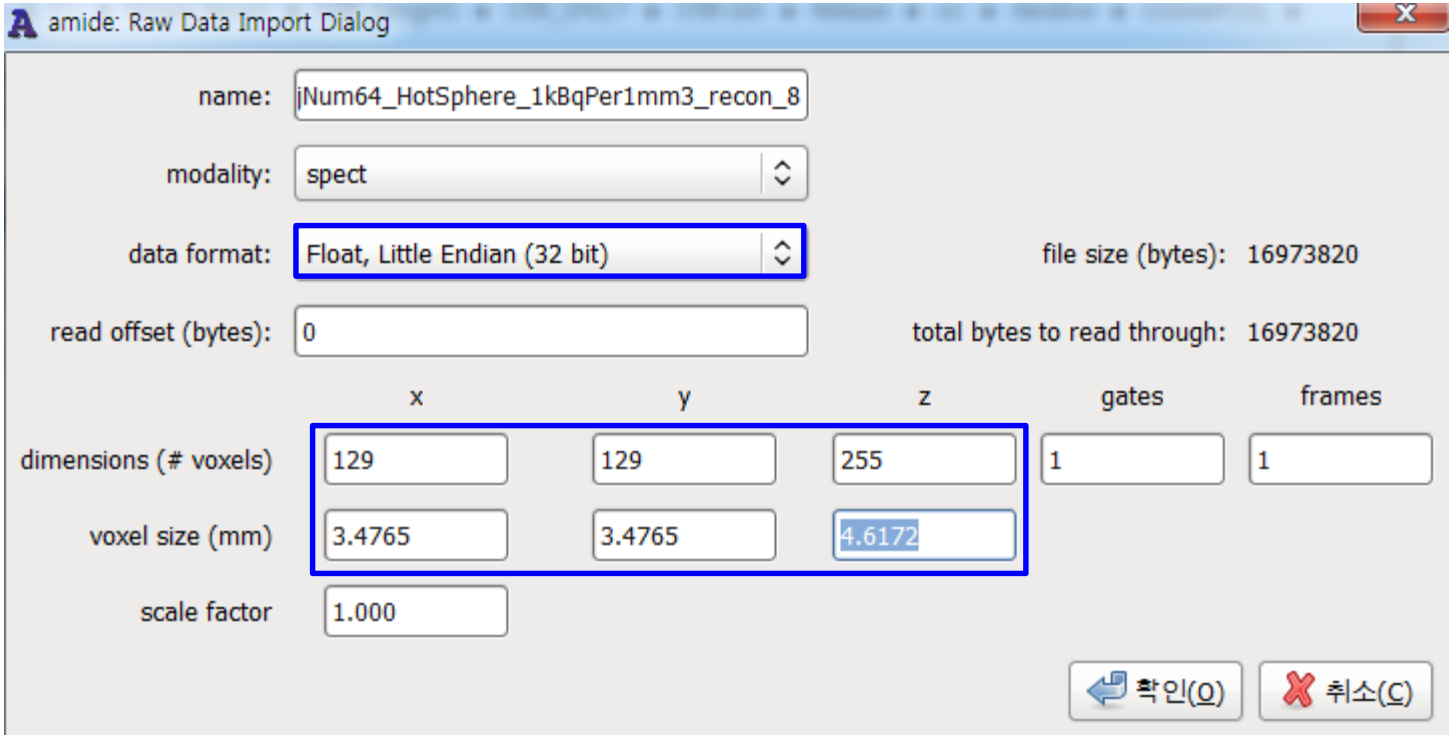
***.hv (header)**

Reconstructed image header file (*.hv)

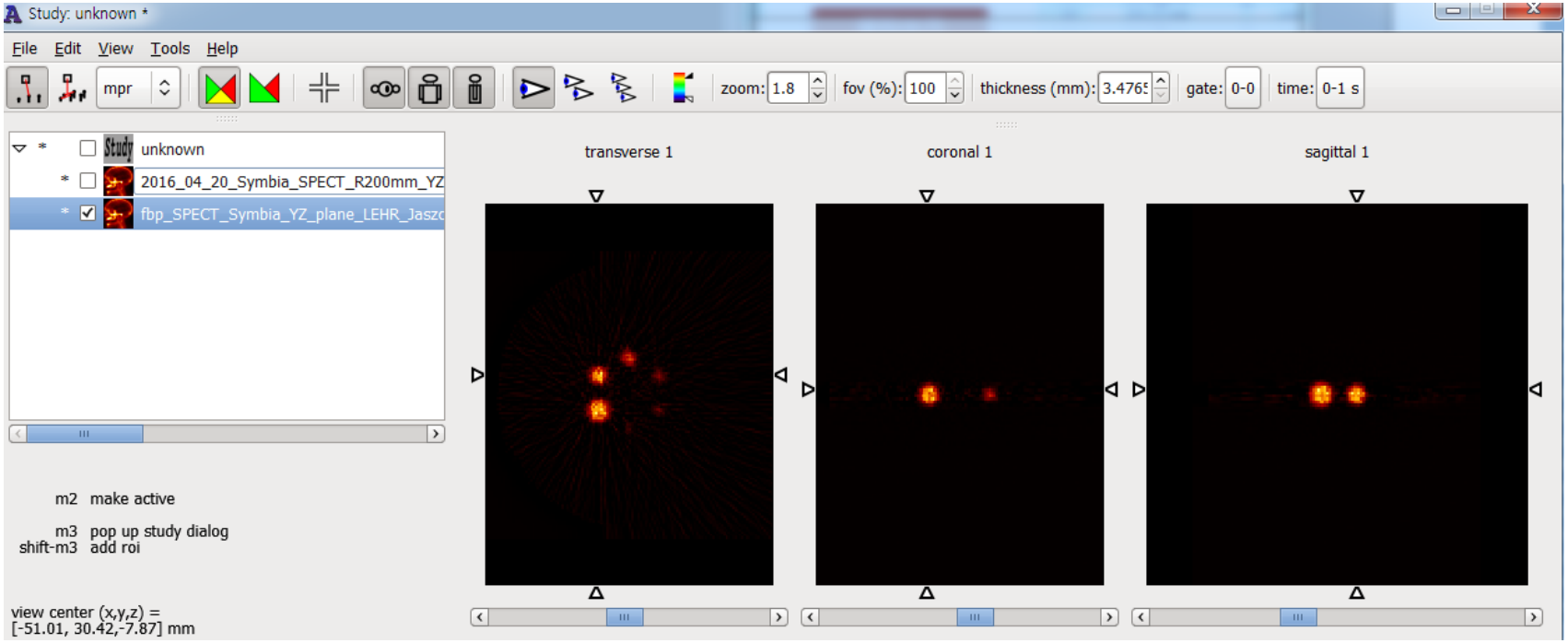
Header files (*.hv) of the Recon image(*.v)

!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** ⟵ Float, 4 bytes/pixel
number of dimensions := 3
matrix axis label [1] := x
!matrix size [1] := **129**
scaling factor (mm/pixel) [1] := **3.4765** ⟵ Pixel size (x) [mm]
matrix axis label [2] := y
!matrix size [2] := **129**
scaling factor (mm/pixel) [2] := **3.4765** ⟵ Pixel size (y) [mm]
matrix axis label [3] := z
!matrix size [3] := **255**
scaling factor (mm/pixel) [3] := **4.6172** ⟵ Pixel size (z) [mm]
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 :=

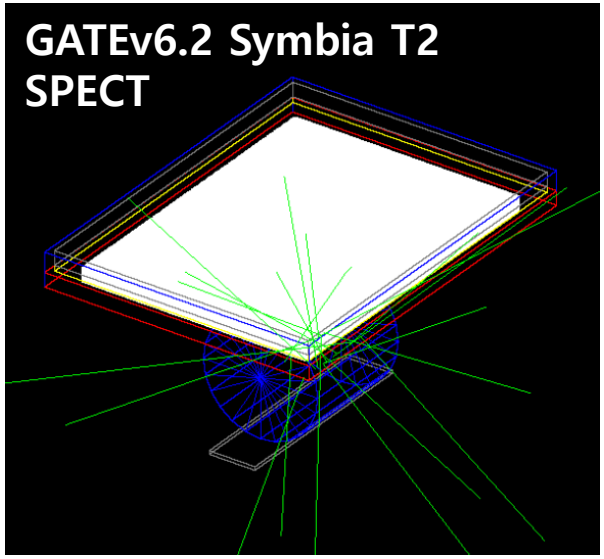
Import the reconstructed image using AMIDE



Import the STIR SPECT Recon image using AMIDE software



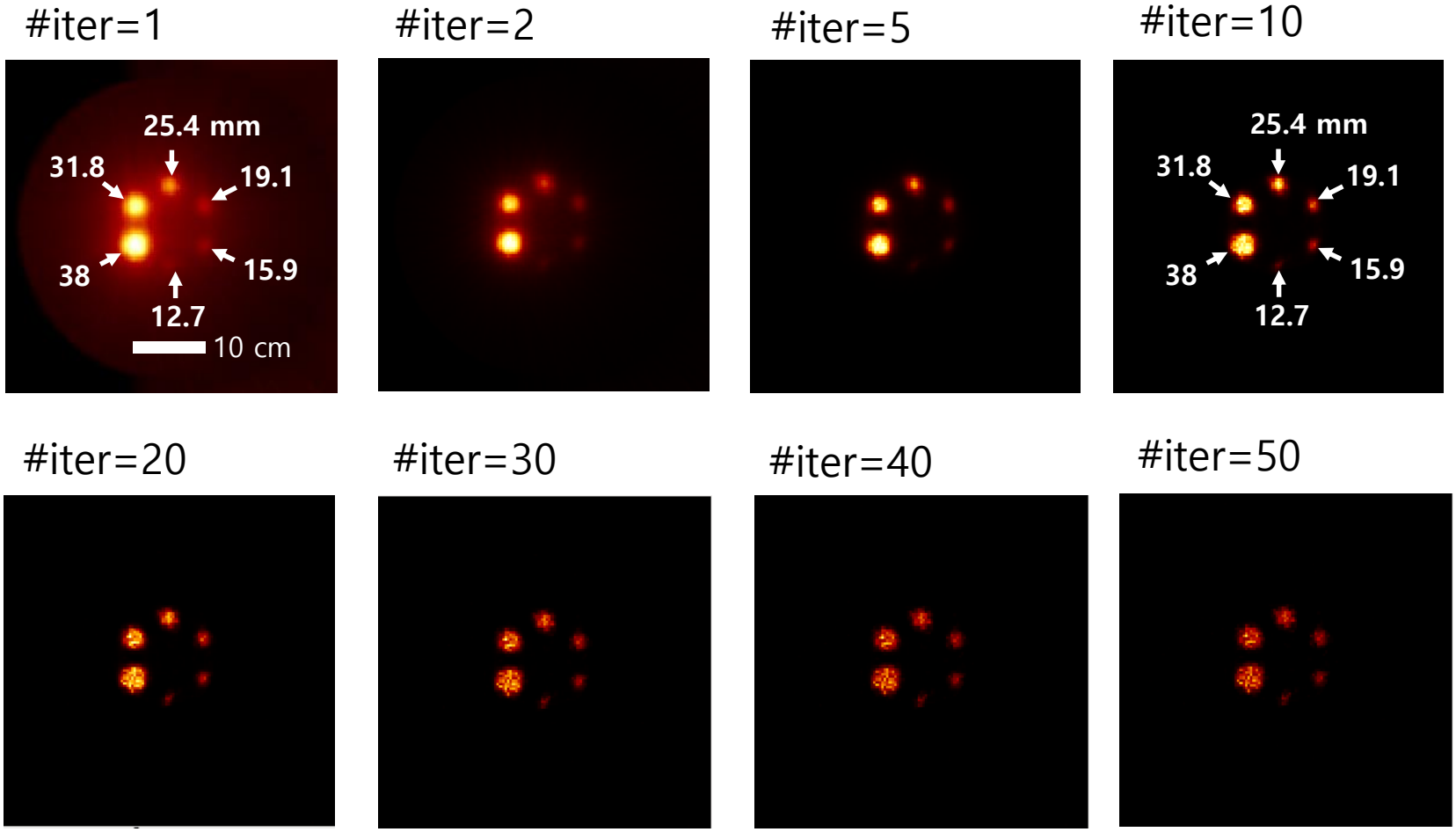
Clinical SPECT simulation using GATE (Siemens, Symbia T2)



#subset = 1

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

SPECT image of Standard Jaszczak phantom (Hot)

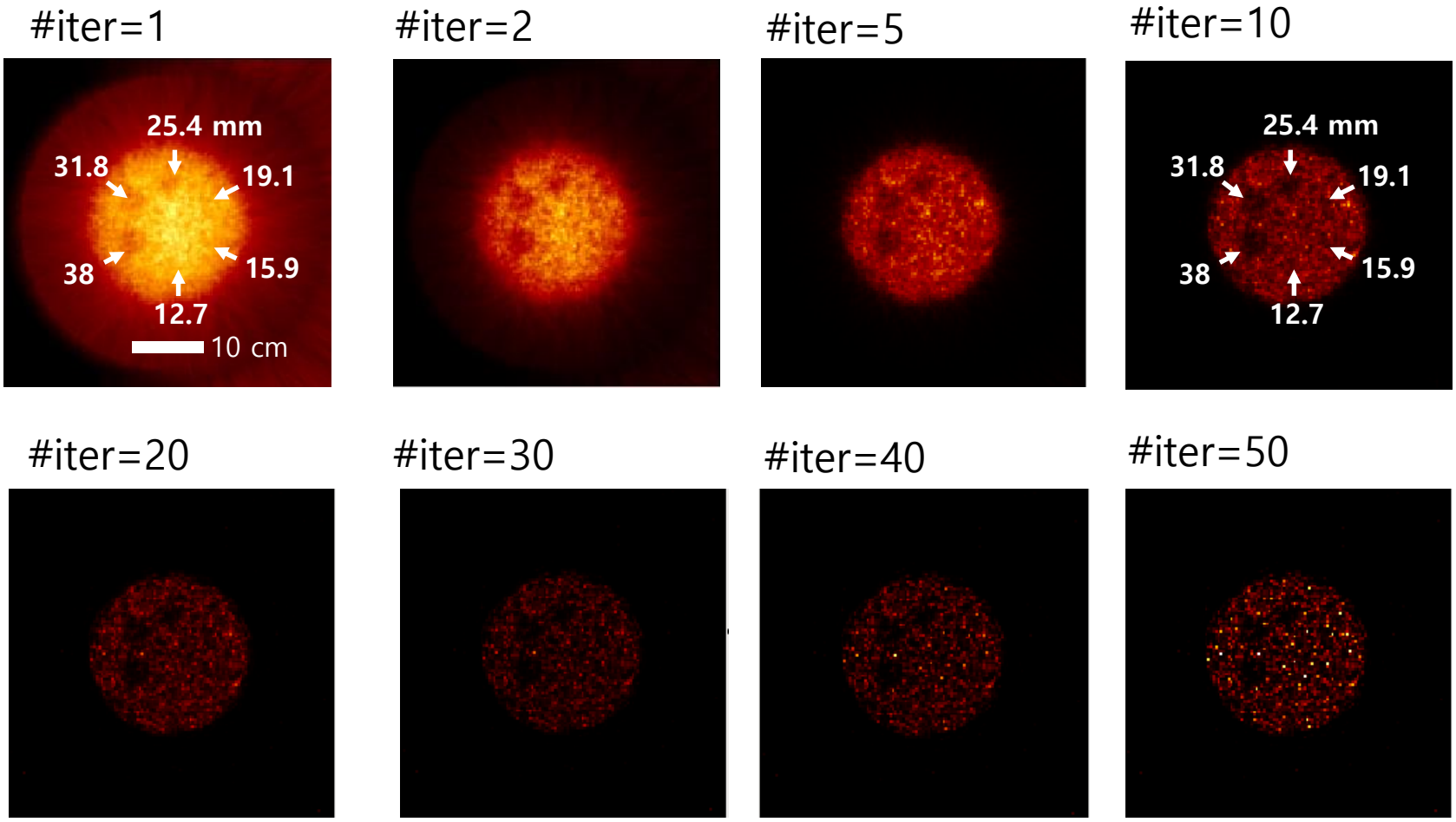


OSMAPOSL (Ordered Subsets Maximum A Posteriori One Step Late) **Unpublished**

#subset = 1

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

SPECT image of Standard Jaszczak phantom (Cold)

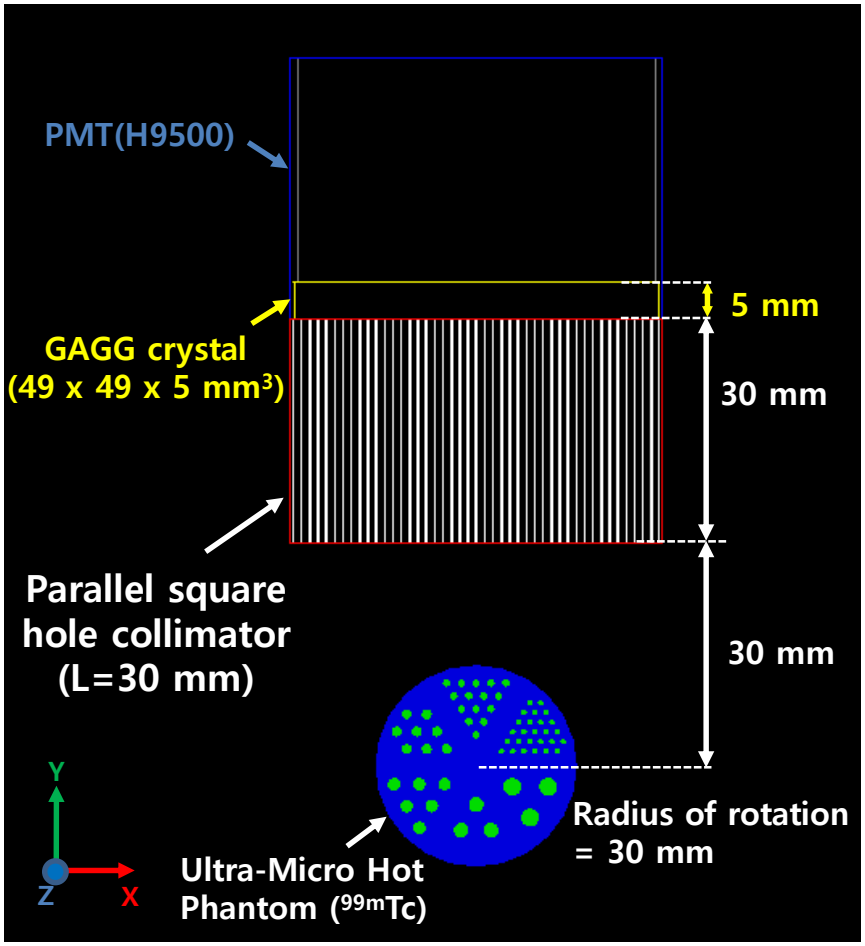


OSMAPOSL (Ordered Subsets Maximum A Posteriori One Step Late) **Unpublished**

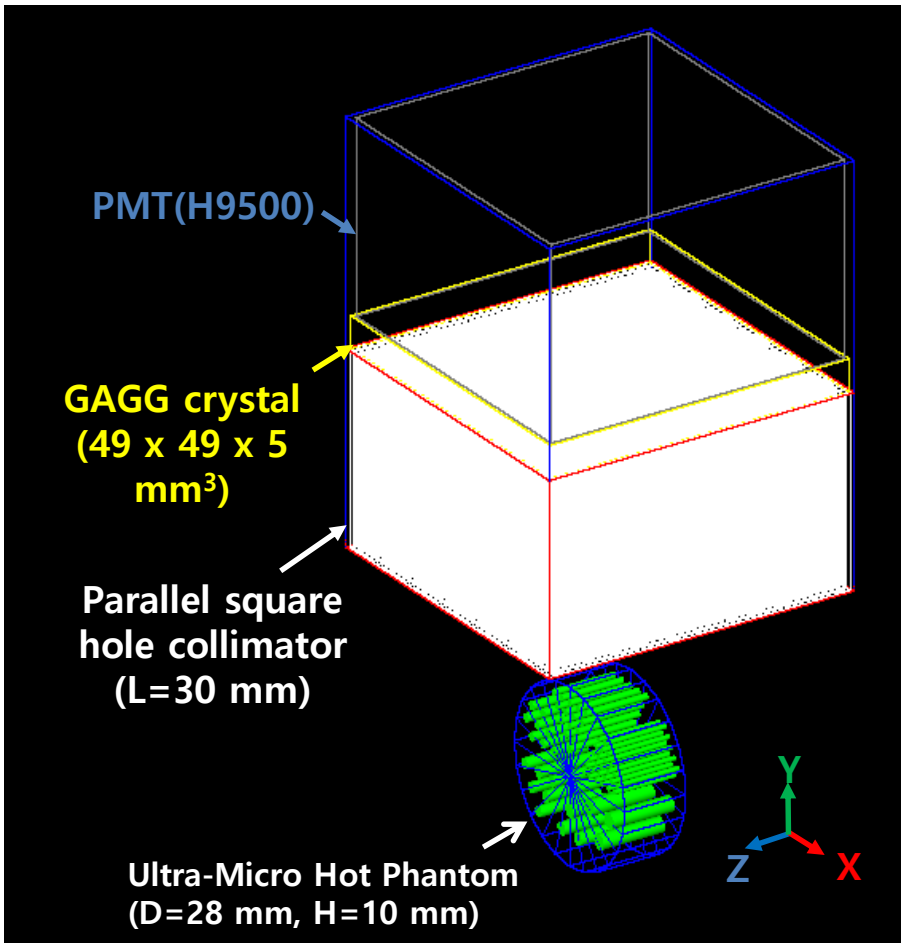
Small animal SPECT simulation using GATE

GATEv6.2 SPECT simulation setup

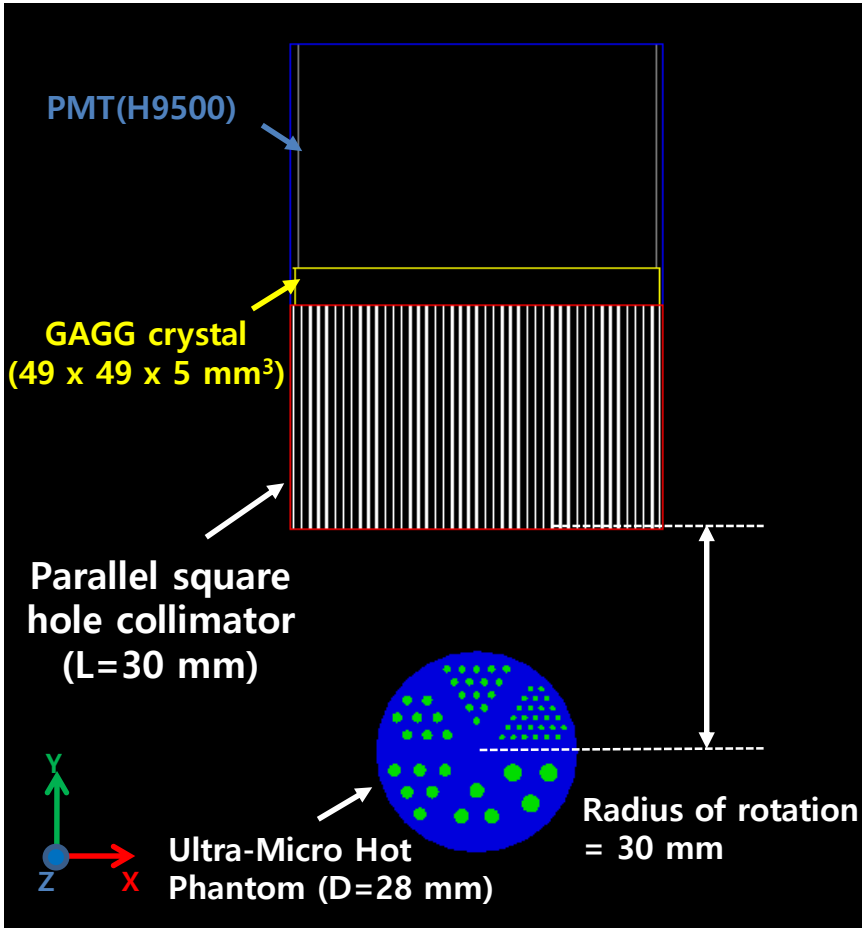
(a) GATE SPECT simulation setup



(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

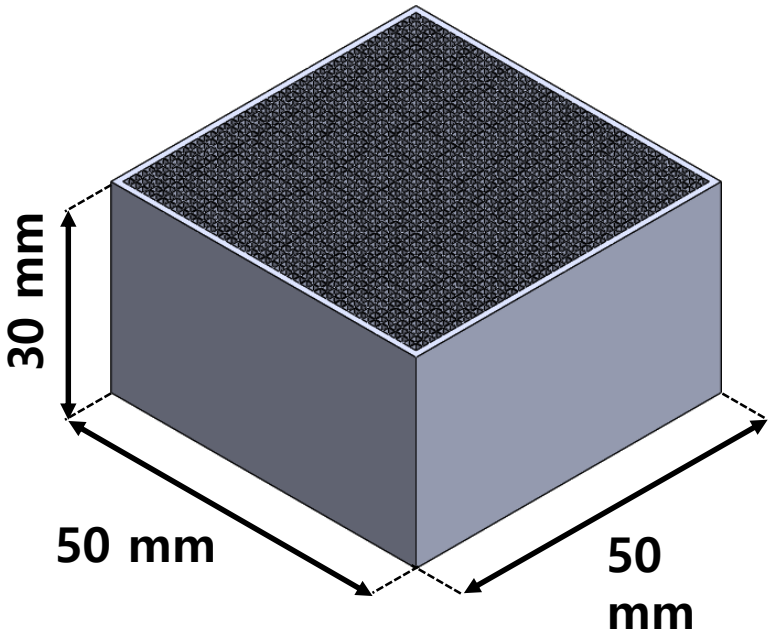
Characteristics	Value
Scintillator	GAGG:Ce
Crystal dimensions [mm]	49 x 49 x 5
#of PMT	1
Diagonal FOV [mm]	69.3
Intrinsic spatial resolution [mm]	1.0 mm
Collimator	**LEHR**
Hole shape	Square
Material	**Tungsten**
Hole length [mm]	**30**
Septa thickness	**0.1**
Hole diameter across the flats	**1.0 mm**

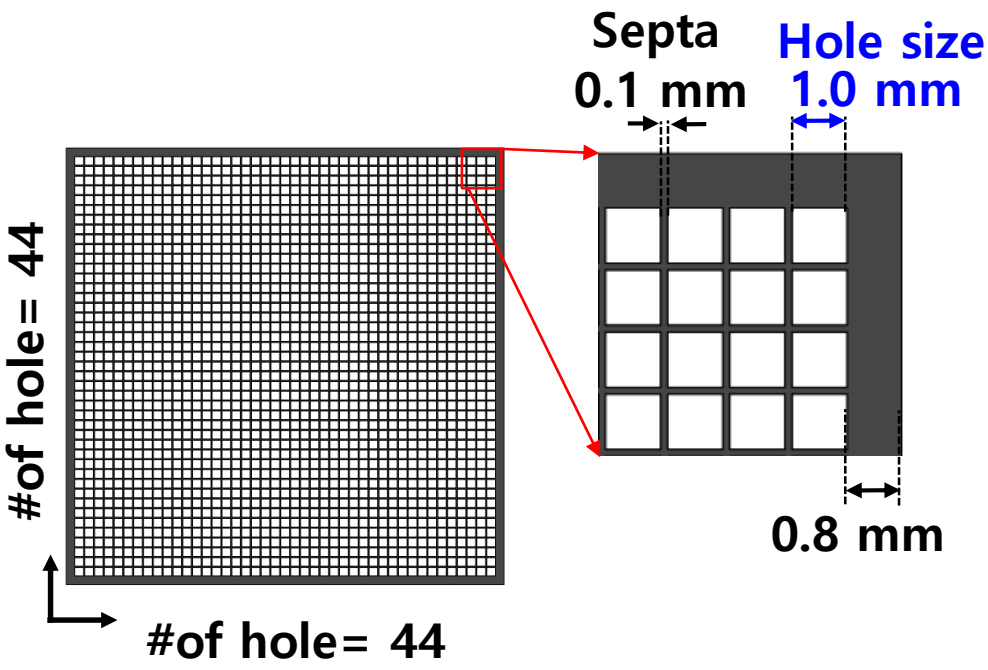
Unpublished

Tungsten square hole parallel collimator

Hole size was changed while the septa was fixed.

<3D view of the collimator>

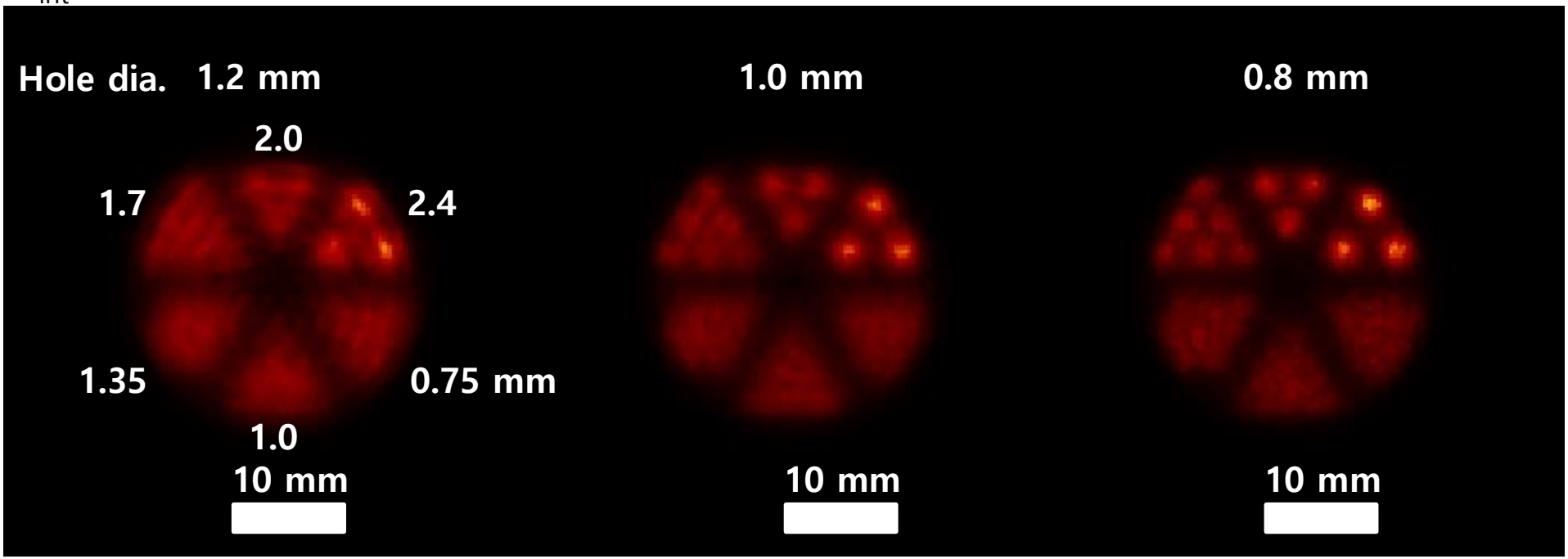




SPECT images of an ultra-micro hot phantom

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

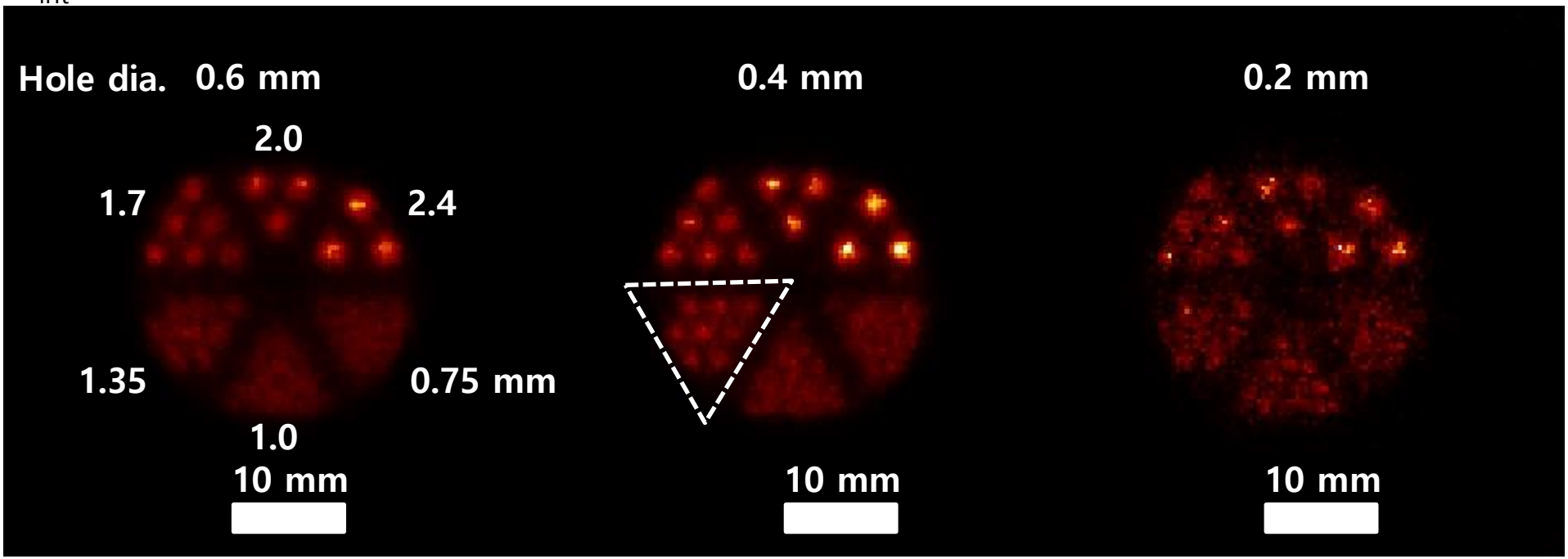
^{99m}Tc activity = 300 [kBq/mL]

Unpublished

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)

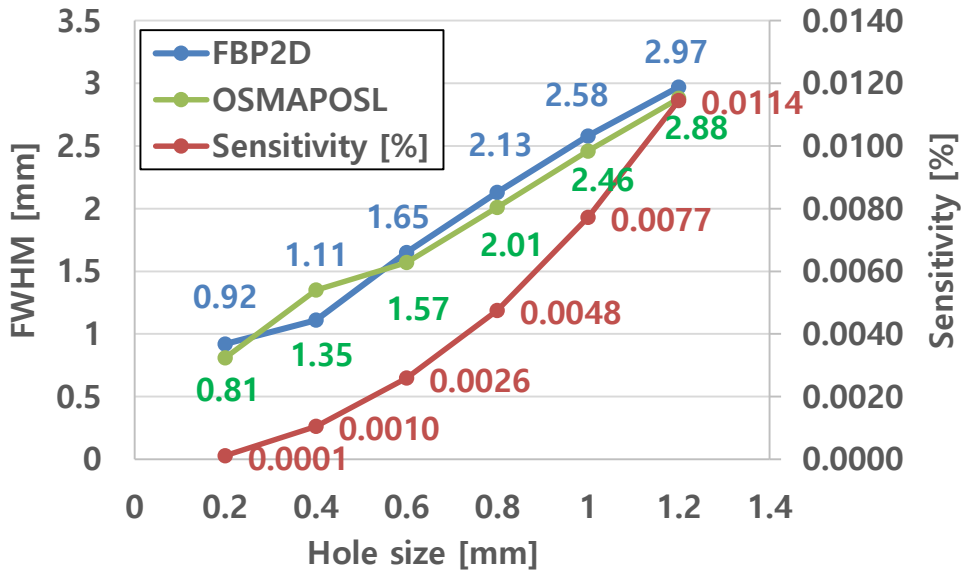


OSMAPOSL (Ordered Subsets Maximum A Posteriori One Step Late): STIR software

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

Unpublished

Spatial resolution and sensitivity depending on the hole size



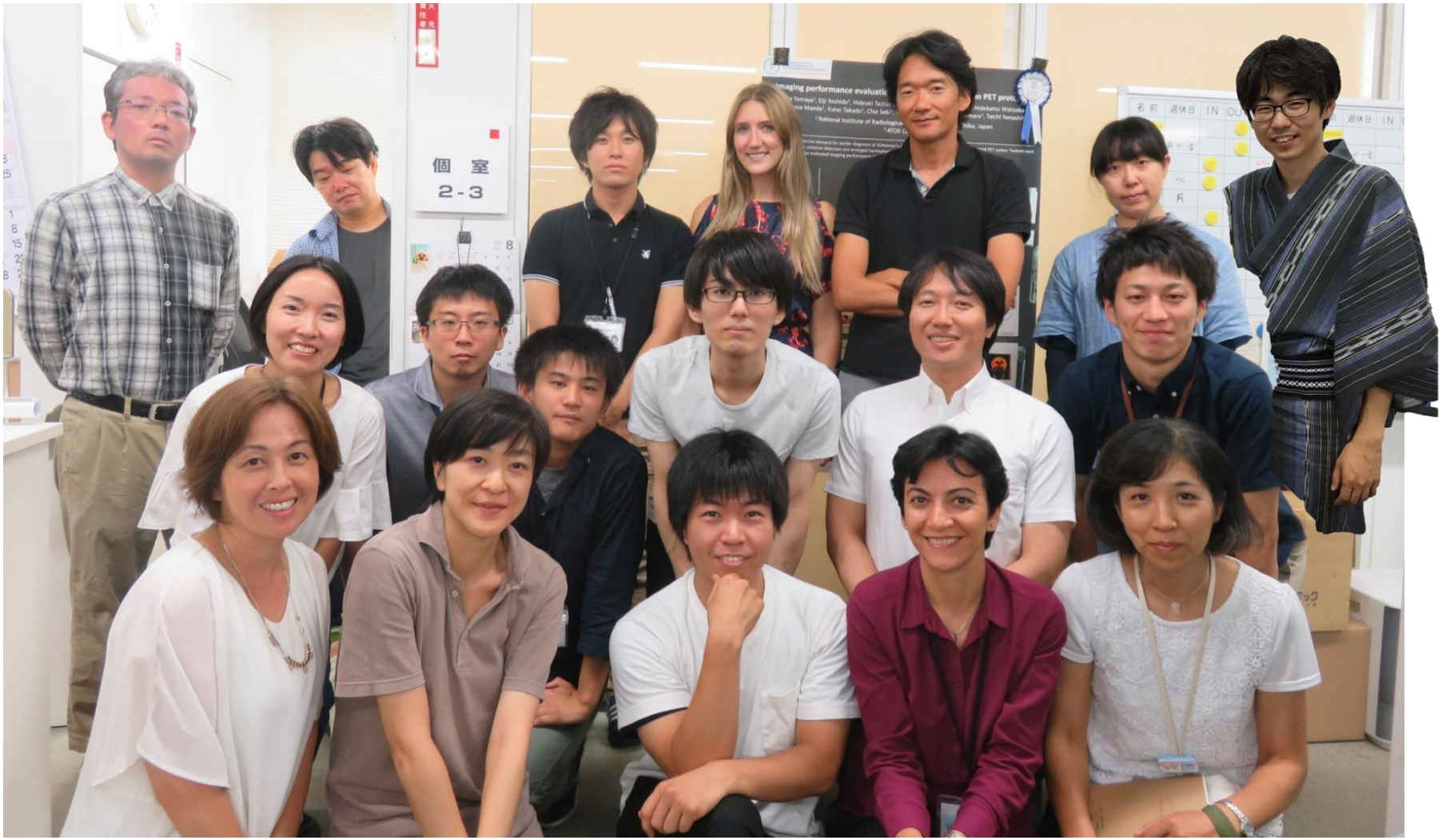
Conclusions

- **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)

hangyookang@gmail.com
kang.hangyu@qst.go.jp

Thank you for your kind attention~!



Thank you for you kind attention.

Han Gyu Kang[1], Hideaki Tashima[1], Seong Jong Hong[1], and **Taiga Yamaya**[1]

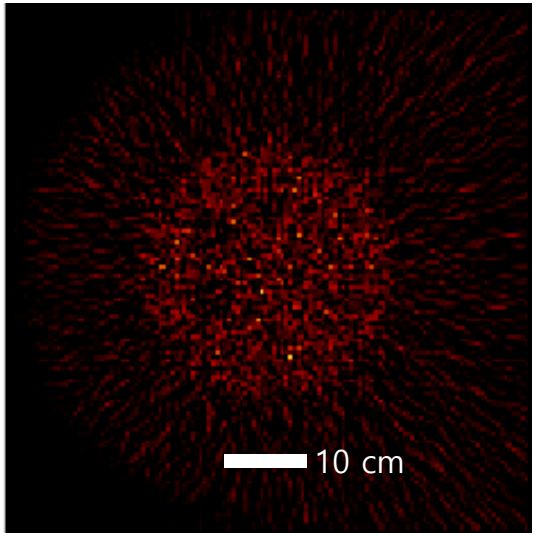
1. National Institute of Radiological Sciences (NIRS) in National Institutes for Quantum and Radiological Science and Technology (QST), Japan
2. Dept. of Radiological Science, Eulji Univ, Korea
3. Dept. of Senior Healthcare, Eulji Univ. Korea

hangyookang@gmail.com
Kang.hangyu@qst.go.jp

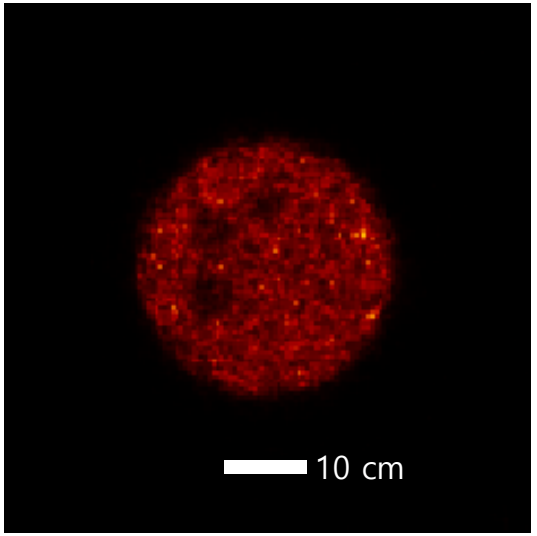
Back up

FBP2D vs. OSMAPOSL (Jaszczak cold phantom)

FBP2D



OSMAPOSL



#subset = 1
#iteration = 10

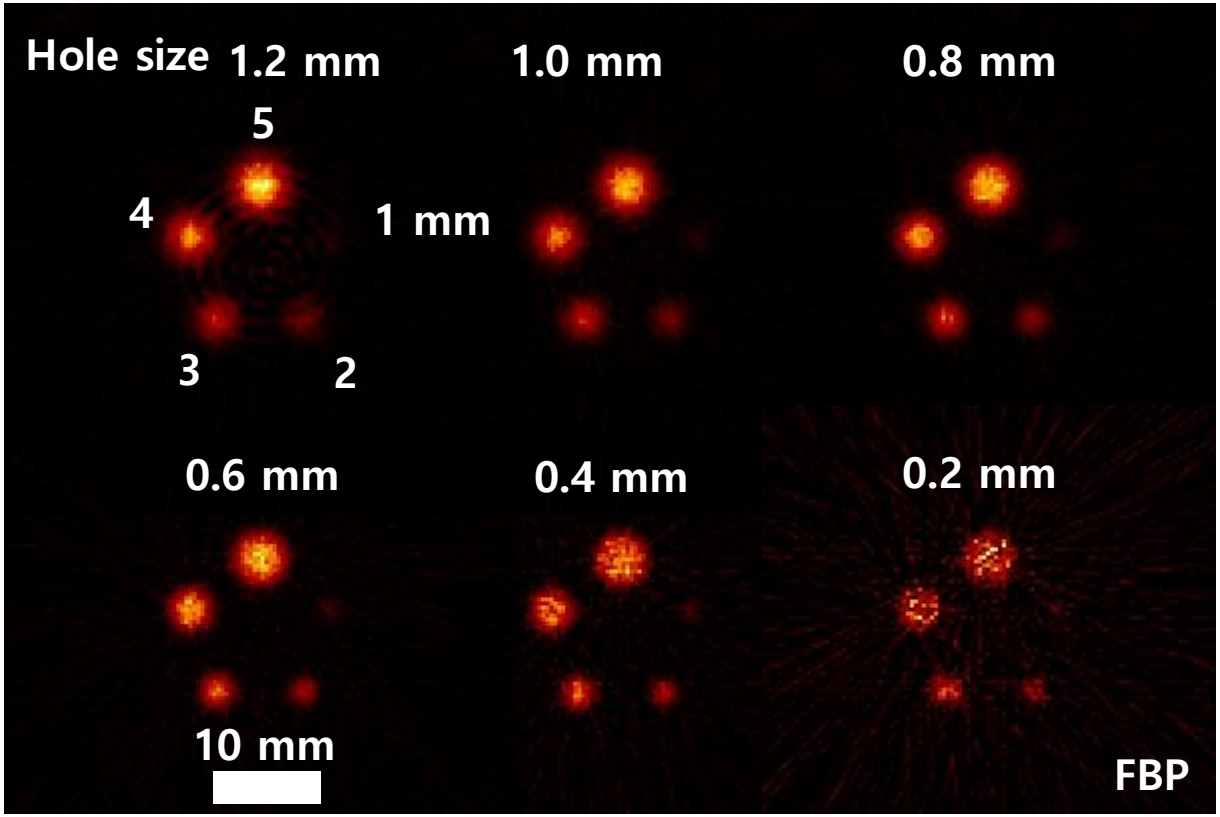
SPECT head rotation= 180°
#Projections =64
Scan time/proj = 1 sec
Rotation speed [degree/sec] = 2.8125

^{99m}Tc concentration = 27 Bq/mm^3
Total ^{99m}Tc activity = 100 MBq

Tungsten collimator

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

Energy range = 140 keV±10%(126~154 keV) FBP2D

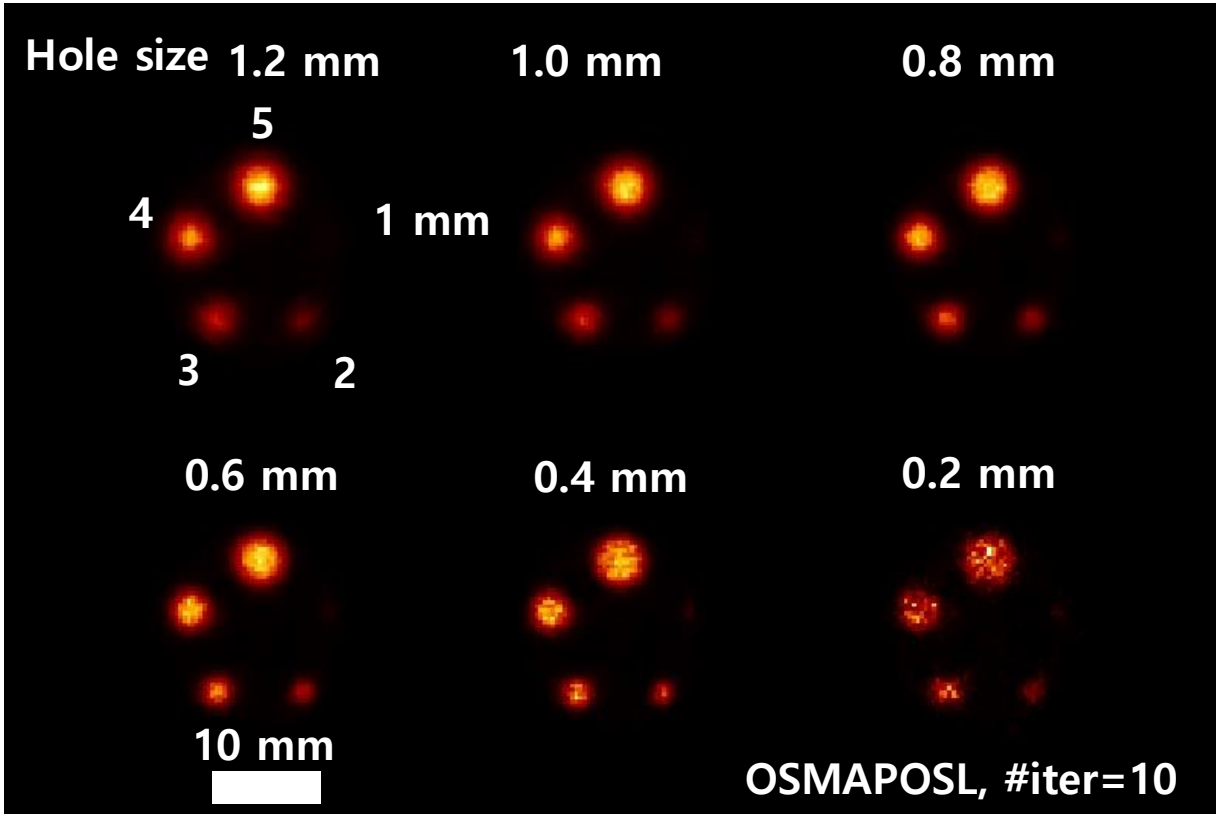


Tungsten collimator

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

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

OSMAPOSL
Subset = 1



Recovery coefficient