Design of a virtual model of a hand-held Germanium detector and a voxelized ICRP whole body phantom: A Monte Carlo study

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Study Objectives

- Development of a Monte Carlo model with a hand held HPGe (High Purity Germanium) detector integrating with a voxelized whole body ICRP phantom
- Study characteristic signatures of medical radionuclide, distributed in voxel organ, as captured externally in the radiation detector

Study Importance

Radiation Detection and Isotope Identification in Security Monitoring

- **Correct identification of a radionuclide is important to discriminate the type: medical, industrial or malicious material.**
- **Each radionuclide produces a characteristic spectral signature with single or multiple peaks (depending on the radionuclide) and a compton tail (depending on the source organ attenuation and scattering).**
- **The conventional isotope identification algorithm follows peak identification principle. However, the screening personnel need standardized spectral signatues of medical radionuclides for decision making.**

The proposed model will generate the characteristic signatures of medical radio nuclides, as distributed in the source organ of human body, captured in external detectors

Introduction

Medical Radio nuclides – Types and Varieties

Divided into two groups based on applications: (i) diagnostic (ii) radio therapeutic

Diagnostic application			Therapeutic applications			
Types of emitters						
Beta or gamma	Positron	Auger Electron	Beta	Positron	Alpha	Auger Electron
^{131}I	^{18}F	^{111}In	^{131}I	^{64}Cu	^{211}At	^{77}Br
^{111}In	^{11}C	^{123}I	^{89}Sr	^{66}Ga	^{223}Ra	^{111}In
^{201}Tl	^{15}O	^{125}I	^{153}Sm		^{225}Ac	^{123}I
^{89}Sr	^{13}N		^{166}Ho		^{149}Tb	^{125}I
^{103}Pb	^{82}Rb		^{90}Y		^{224}Ra	^{67}Ga
^{192}Ir	^{68}Ge		^{177}Lu		^{212}Bi	^{201}Tl
^{153}Sm	^{60}Cu		^{149}Pm		^{213}Bi	^{51}Cr
^{166}Ho	^{64}Cu		^{199}Au		^{227}Th	^{140}Nd
^{99m}Tc	^{61}Cu		^{64}Cu		^{255}Fm	^{195m}Pt
^{90}Y	^{76}Br		^{186}Re			
^{175}Yb	^{77}Br		^{188}Re			
^{166}Dy	^{124}I		^{67}Cu			
	^{94m}Tc		^{117m}Sn			
	^{86}Y		^{32}P			
	^{89}Zr		^{165}Dy			
	^{66}Ga		^{105}Rh			
	^{68}Ge / ^{68}Ga		^{111}Ag			
	^{30}P					
	^{34m}Cl					

Source: PNNL document: 19294, 2010; Valkooovic 2006, J Phys

Introduction

Medical Radionuclide and Radio pharmaceuticals

Properties and Function

- For clinical purpose, the radio nuclides are combined with pharmaceuticals before they are injected into the patient's body.
- The radio pharmaceuticals distribute in the body and accumulates in the target organ.
- The distribution of the radio pharmaceuticals inside, is imaged externally by detectors
- The radio pharmaceuticals excrete out of the body with a biologic half life and also undergo physical decay
- From security perspective, the clinical procedures where multiple radio nuclides are used in parallel, or in consecutive studies, create a false peak or false radio nuclide identification, resulting a false alarm.

Introduction

Medical Radio nuclides – Types and Varieties

Properties of diagnostic and therapeutic radio pharmaceuticals

Parameters	Types of radio pharmaceuticals	
	Diagnostic	Therapeutic
Types of Emission	**In general, pure gamma emitter; decay by either electron capture or isomeric transition**	**The preferred mode of decay is pure beta-minus emission.**
Energy	**Ideal imaging energy range is 100 to 250 keV**	**No exact energy range; In general, E_{max} ☐ 1 MeV**
Chemical reactivity	**Ideal radio pharmaceutical for diagnostic imaging readily binds to a wide variety of compounds under physiological conditions.**	**Therapeutic radio-pharmaceuticals are very target specific**
Target-to-nontarget ratio	**Distinguish pathology from background; target : non-target ☐ 5:1**	**Target-to-nontarget is essentially high.**
Effective half-life	**Measured in 'hours'**	**Measured in 'days'**

Source: Nuclear Medicine, Henkin et. Al., 1996

Materials

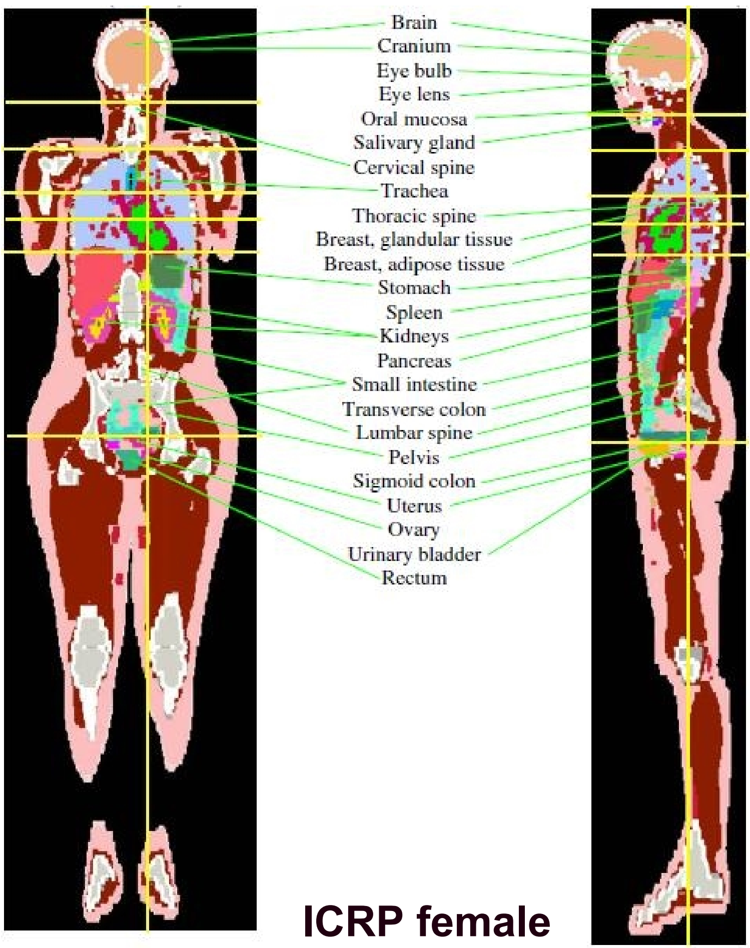
Micro Detective System

Micro–Detective®–HX
ORTEC
Oak Ridge, TN, US

- **Portable, easy handling and operation**
- **Perforated sealing against moisture, dust**
- **Wireless communications**
- **Visual, auditory and vibrating alarm**
- **Built-in comprehensive nuclide data library of more than 100 radioisotopes**
- **Discrimination capability: legitimate sources (e.g. medical or industrial radioisotopes) and malicious radioisotopes (e.g. radiological dispersal device)**
- **MicDet has 40 fold better energy resolution (selectivity) than the nearest alternative**

Materials

ICRP voxel phantom



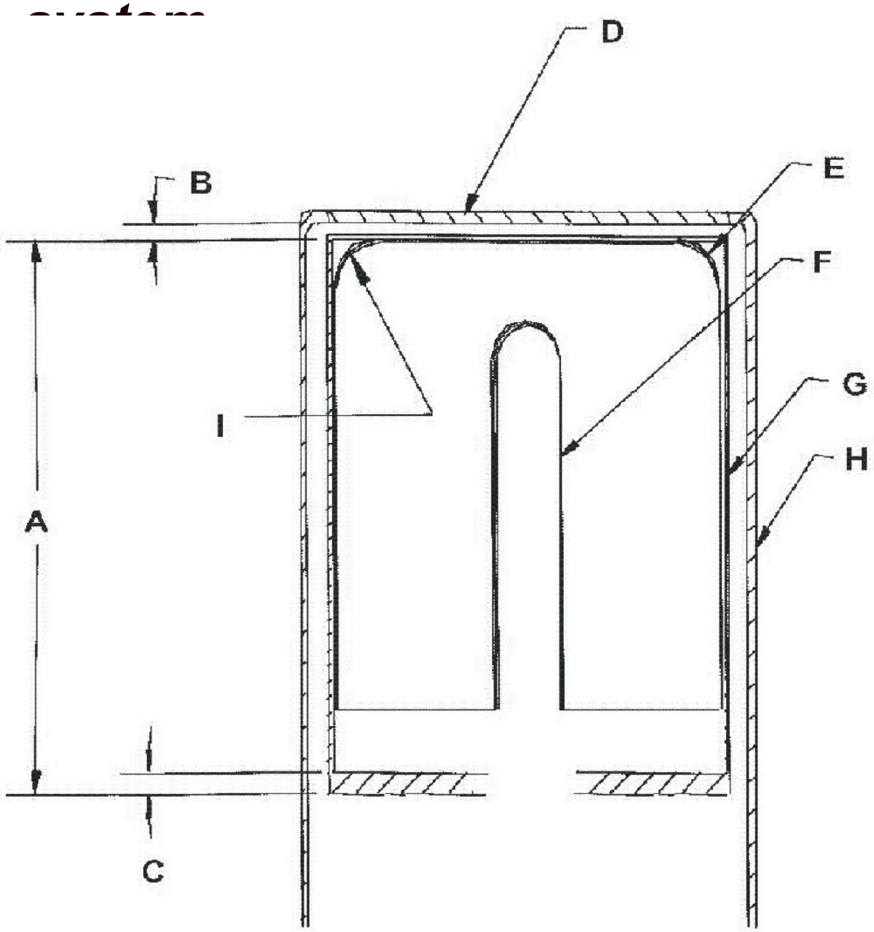
ICRP female voxel phantom

- **Reference Female: ICRP 110, 2009**
- **Constructed from images of real people**
- **Consistent with the organ specification given in ICRP 89, 2002**
- **The organ masses were adjusted to the ICRP data on the adult reference phantoms**
- **The female phantom was based on the CT data, 43-year old, height 167 cm and mass 59 kg;- scaled to 163 cm and 60 kg (Ref. Fem:)**
- **The data set consist of total 346 slices; 174 (5 mm) from head and trunk; 43 (20 mm) from hands & legs; each with 256□256 pixels.**

- **The voxel size = 1.875□1.875□5 □ 17.6 mm^3.**

Methodology

Monte Carlo Model of the detection system



The schematic diagram of the MicDet system

- MCNPX was used [McnpX 2005]
- Pulse height analyzer (F8 tally) was used
- The histogram was binned at 1.0 keV energy window
- The source energy was varied over 50 to 550 keV
- The minimum source to detector distance: 50 cm

A. Mount cup (Al)
B. End cap to crystal gap
C. Mount cup base (Al)
D. End cap window (Al)
E. Out contact (Ge(w/Li ions))
F. Hole contact (Ge(w/B ions))
G. mount cup wall (Al)
H. end cap wall (Al)
I. Detector end radius=0.8 cm

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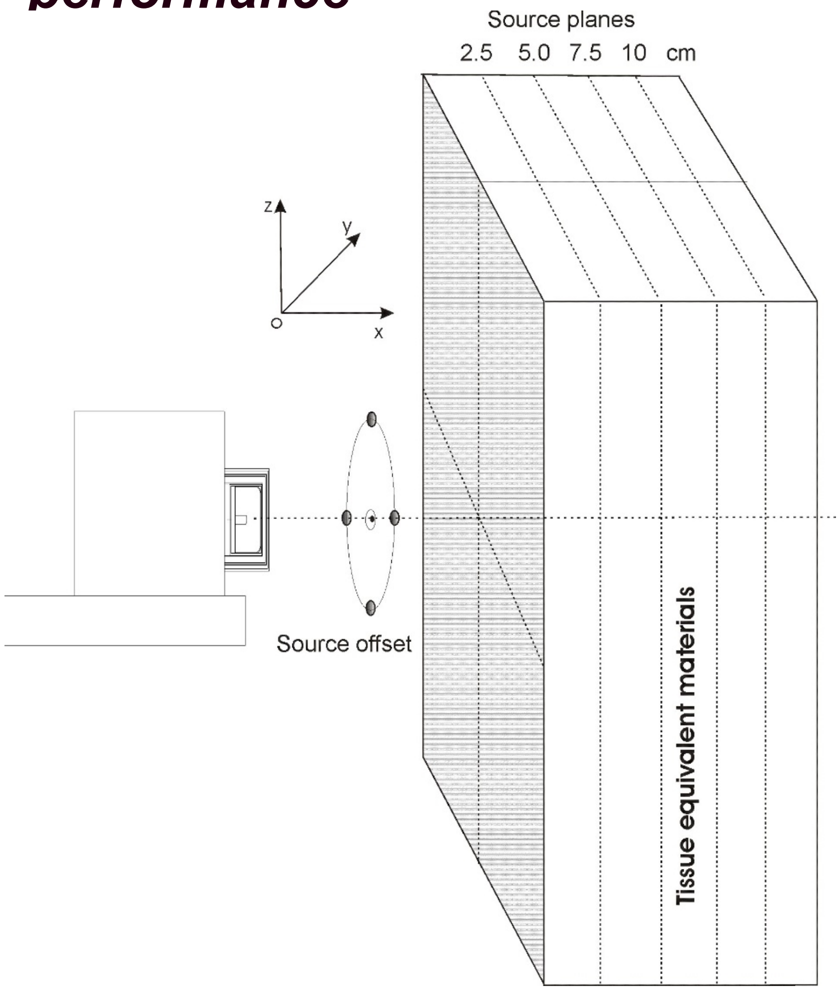
Methodology

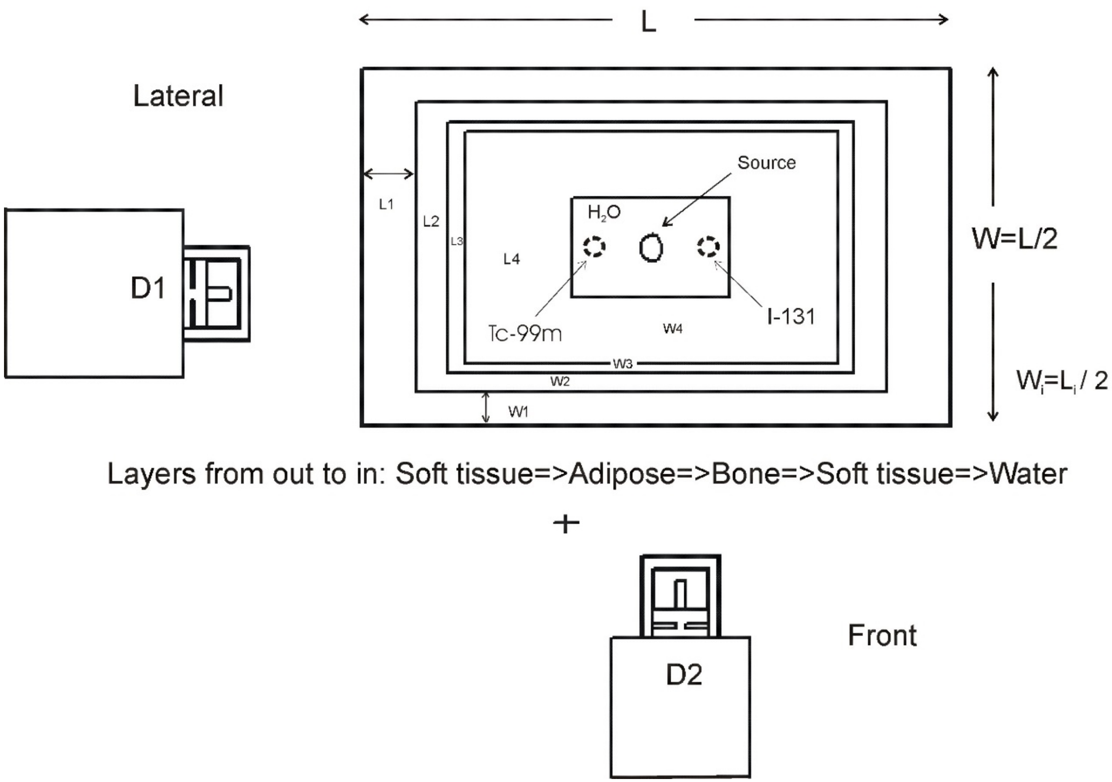
Monte Carlo Model of the detection system – Detector performance



- The pulse height histogram was generated using the F8 tally of MCNPX.
- The histogram was binned with an energy window of 1.0 keV.
- The source energy was varied within the range of 50 to 550 keV.
- Attenuating medium, consecutive studies were performed by placing a point source (sphere of radius 0.5 cm) at different depths inside tissue equivalent material.
- The detector to source distance was varied from 50 to 1000 cm.

Methodology

Monte Carlo Model of the detection system – Multilayer medium



- **The innermost medium is a water tank**
- **The single source positioned at the centre of water tank**
- **Multiple point sources were positioned horizontally, near the lateral ends**

Multi-layer heterogeneous attenuating medium. The width of medium is half the length (W = L/2).

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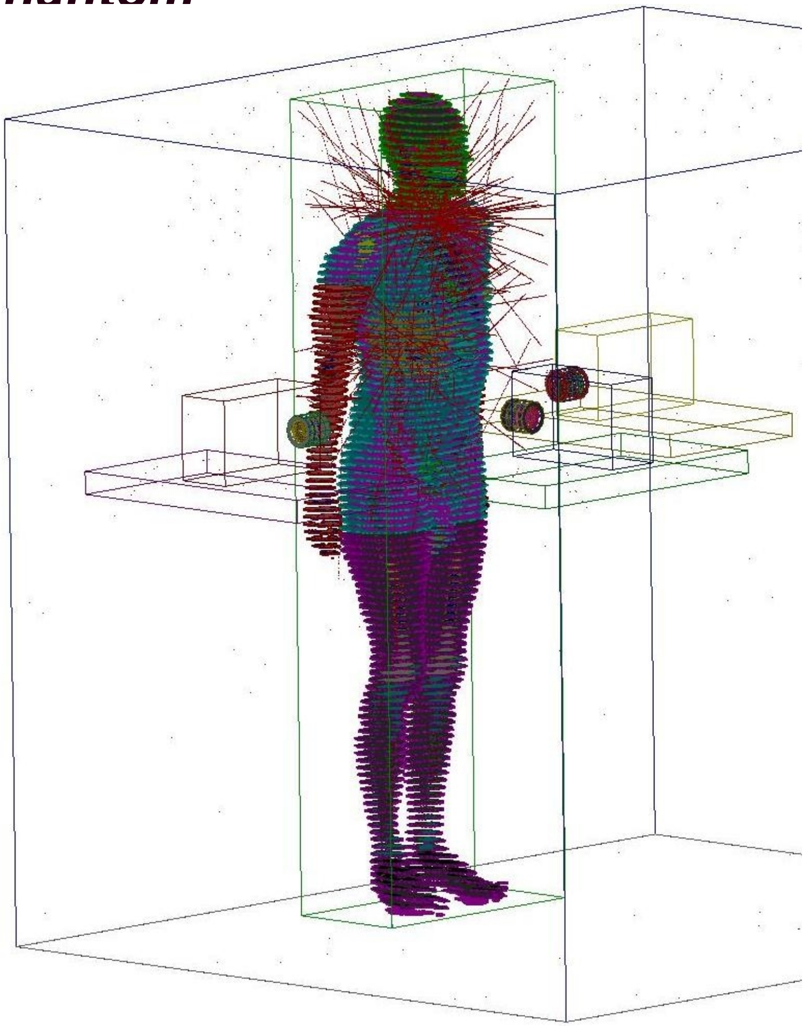
Methodology

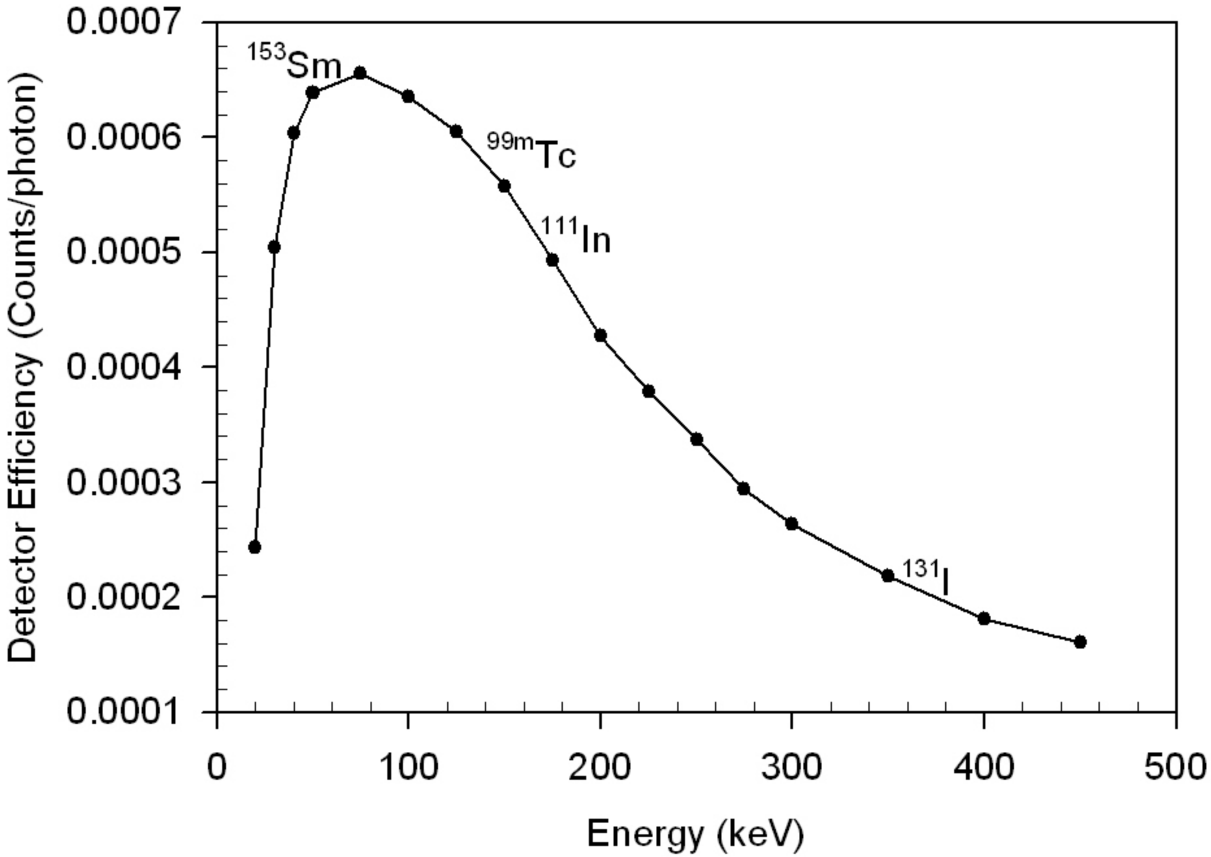
Monte Carlo Model of the detection system – ICRP voxel phantom



- Moritz view of the ICRP voxel phantom
- 99mTc was distributed in the liver and 131I was distributed in the thyroid
- Three detectors captured signatures from three projections: Right Lateral (RL), In front and Left lateral (LL)

Results and Discussion

Micro Detective performance Characteristic



Efficiency decreases about 155% , when photon energy goes down from 140 keV (^{99m}Tc) to 364 keV(^{131}I).

For ^{99m}Tc (E = 140 keV), the detection efficiency (source in air) decreased 117 fold when the source was moved from 50 to 450 cm.

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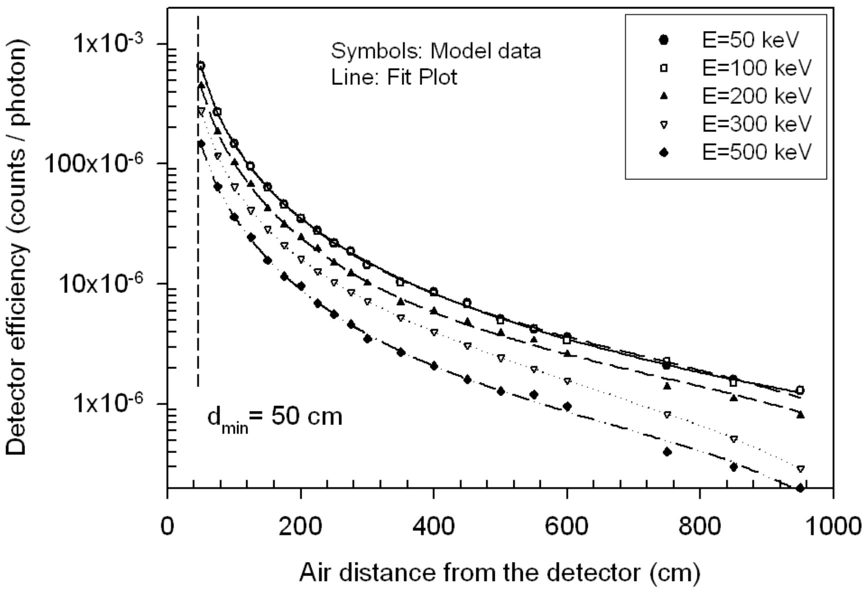
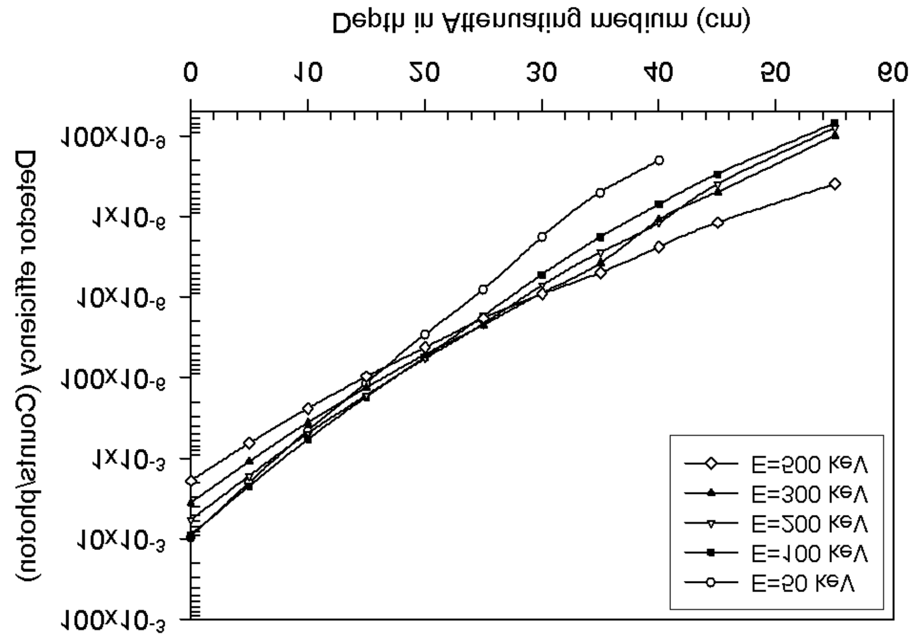
Results and Discussion

Micro Detective performance Characteristic



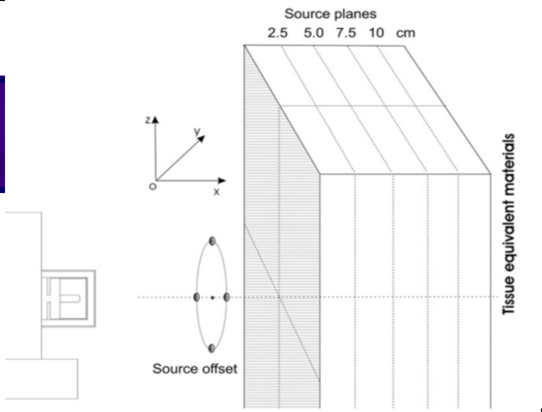


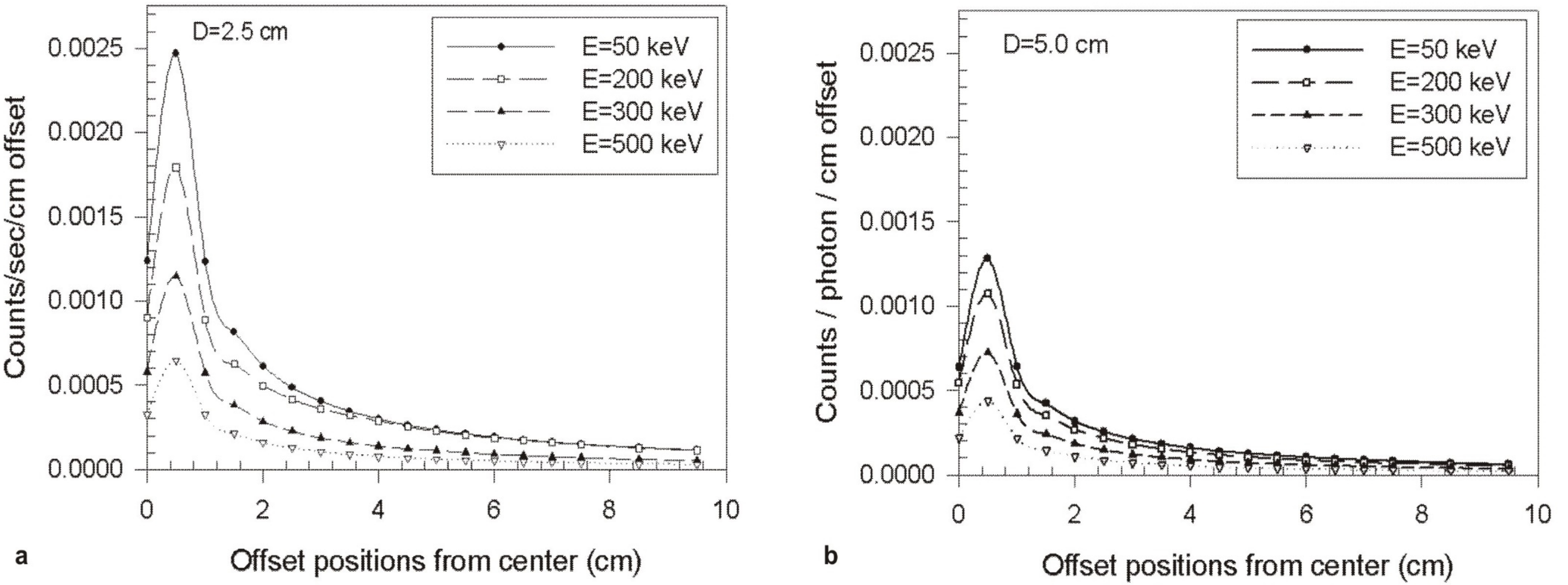
Point source in front of the detector. Detection efficiency decreases following inverse square of the distance.

The attenuation curves for a point source in homogeneous tissue equivalent material. The point source was moved along the detector axis.

Results and Discussion

Micro Detective performance Study : Off Axis Source

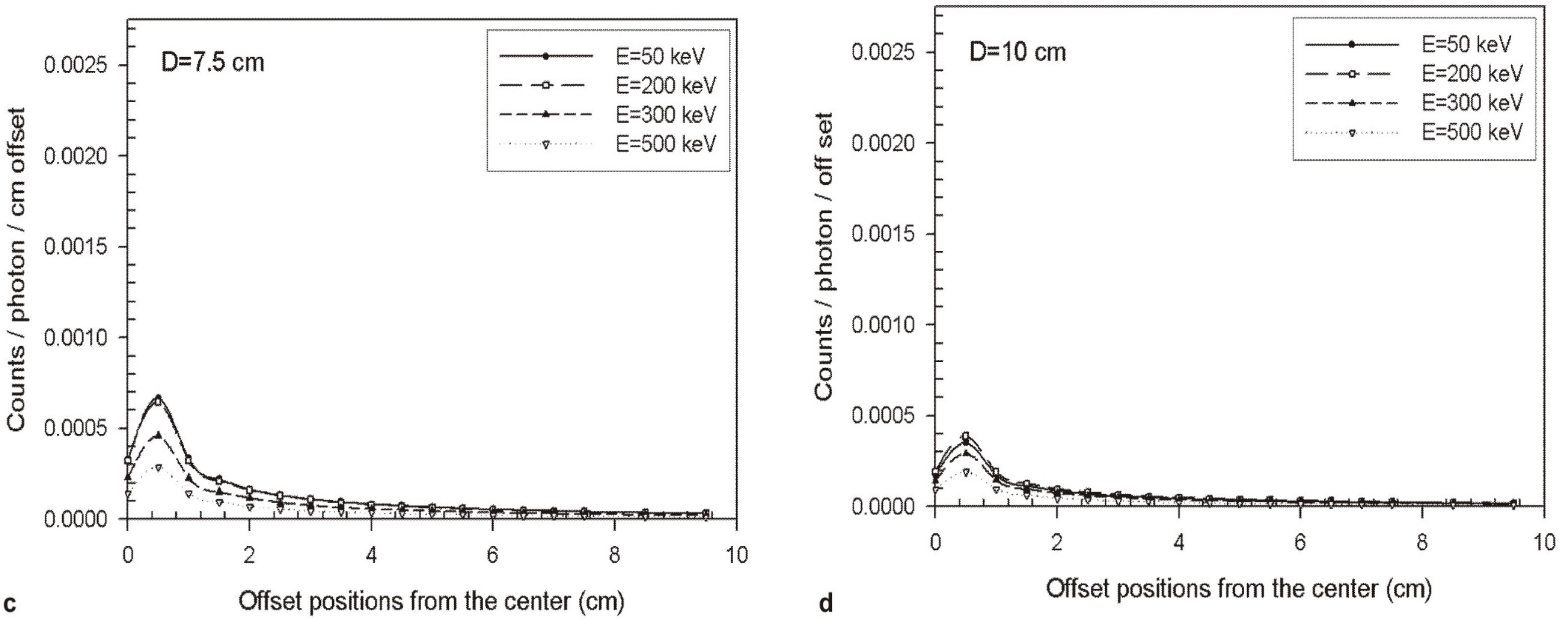




Off-axis point- source. The source-plane embedded inside the tissue equivalent material at (a) 2.5 (b) 5.0 cm depths.

Results and Discussion

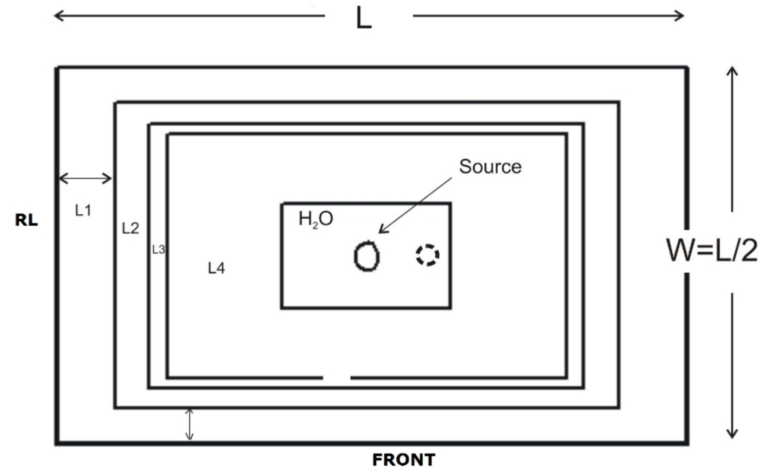
Micro Detective performance Study : Off Axis Source



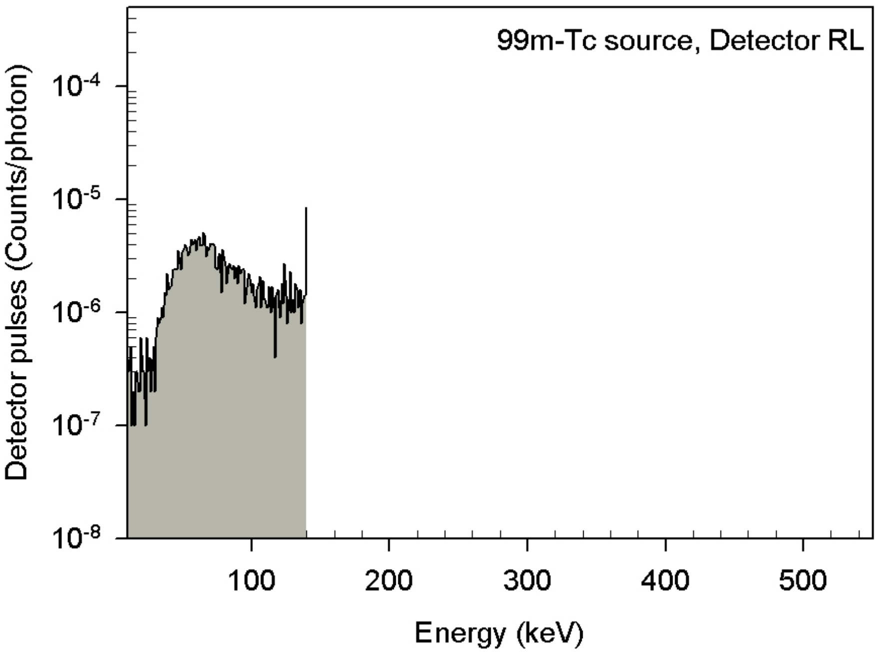
The source-plane embedded inside tissue equivalent material at:

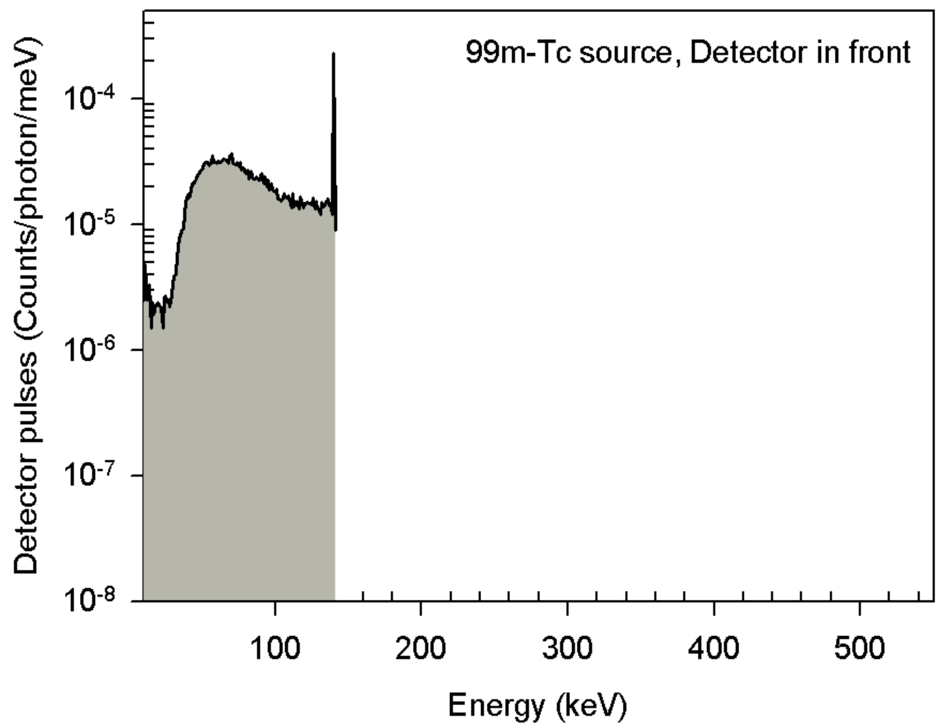
(c) 7.5 and (d) 10 cm depths.

Results and Discussion



Micro Detective performance Study :
Multi layer





For longer attenuating path, some secondary peaks are observed; For ^{99m}Tc

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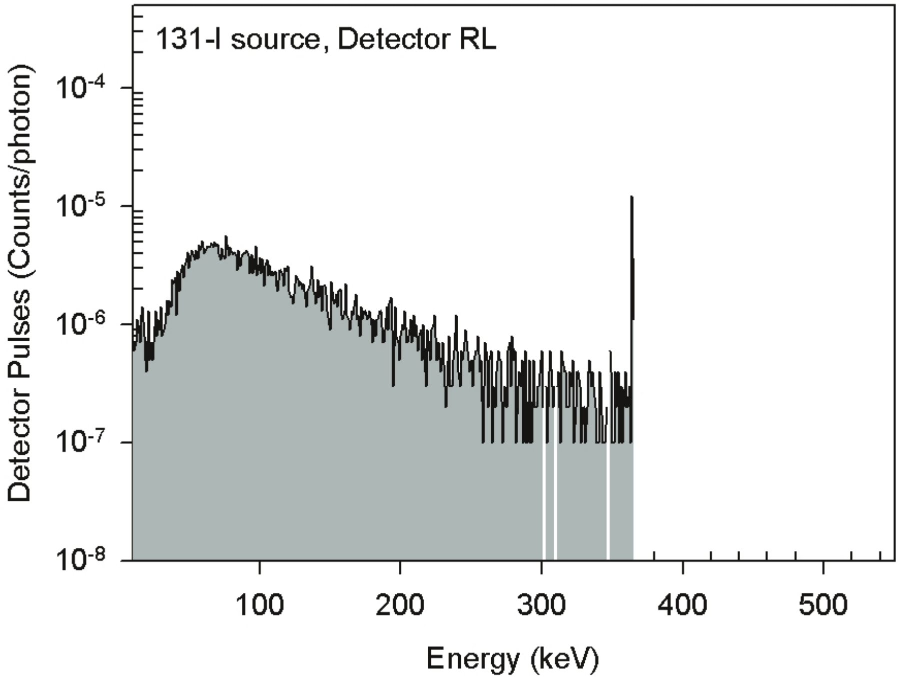
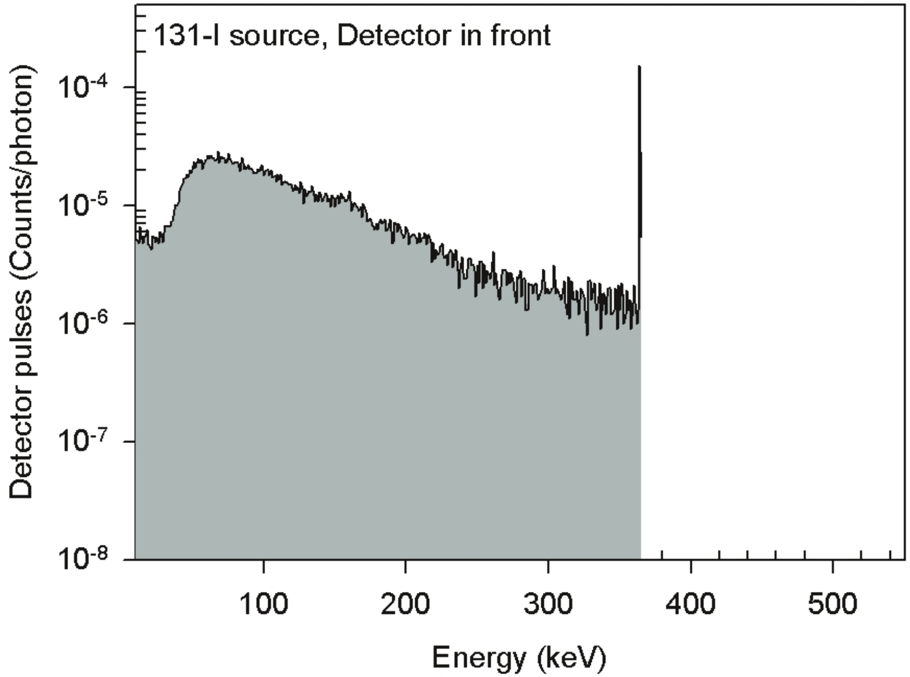
Results and Discussion

Micro Detective performance Study : Multi layer

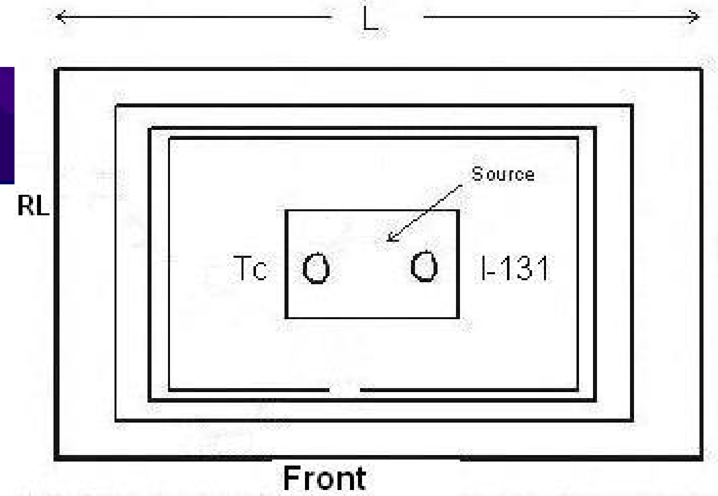


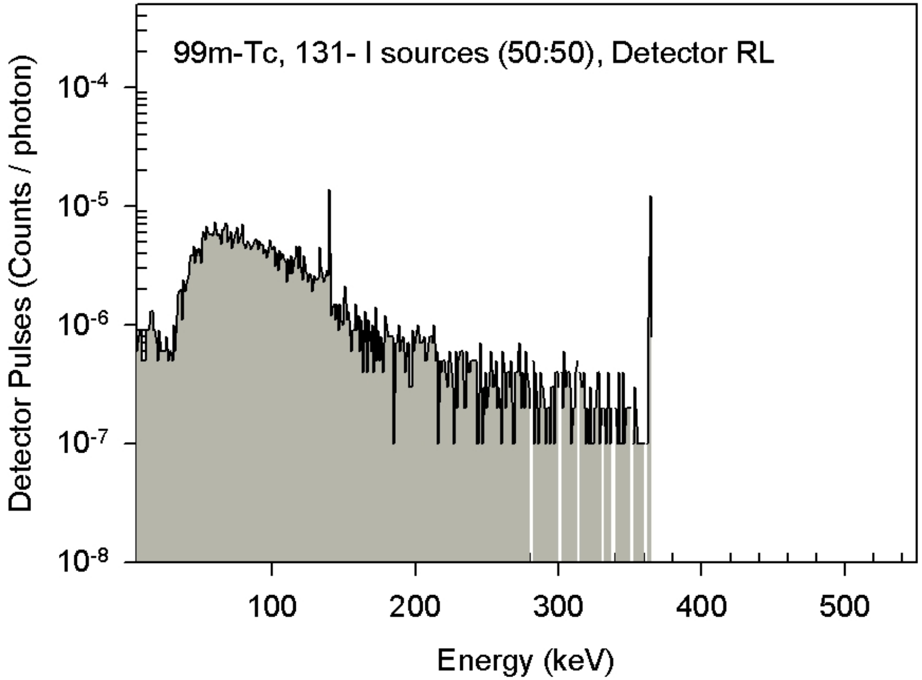


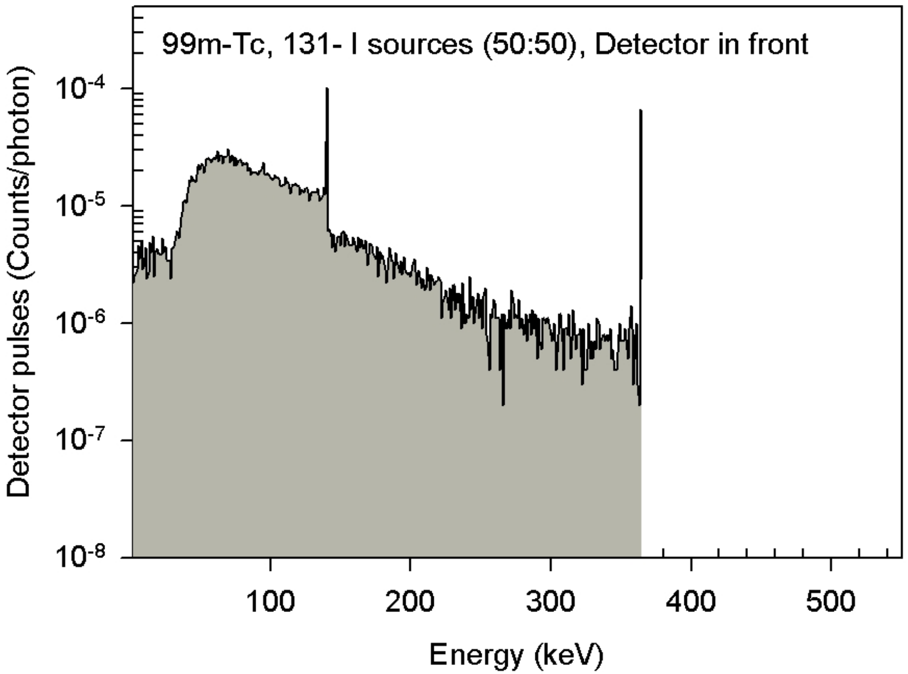
For longer attenuating path, some secondary peaks are observed; For ^{131}I

Results and Discussion

Spectral Signature - Micro Detective System – Isotope combination





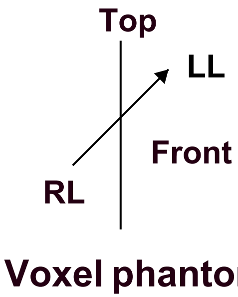


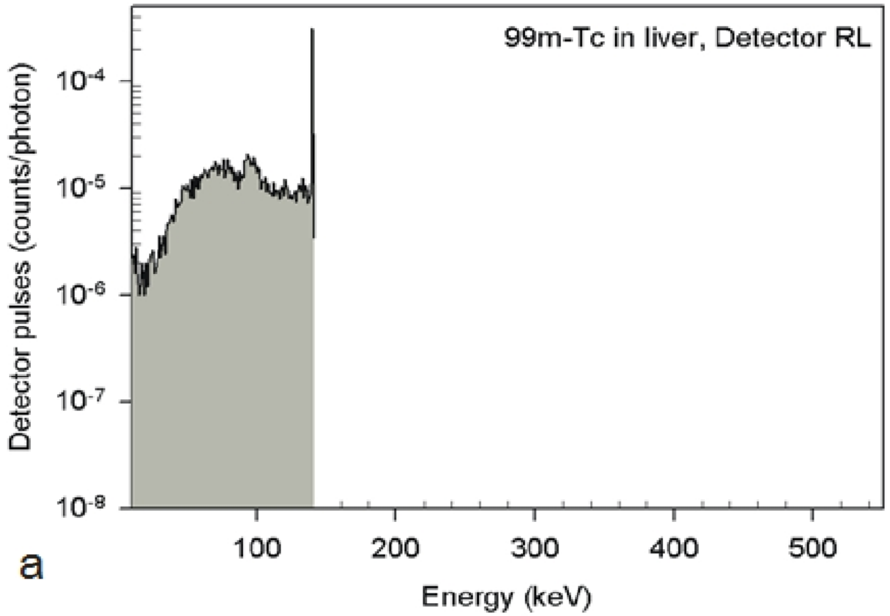
Spectral signature:

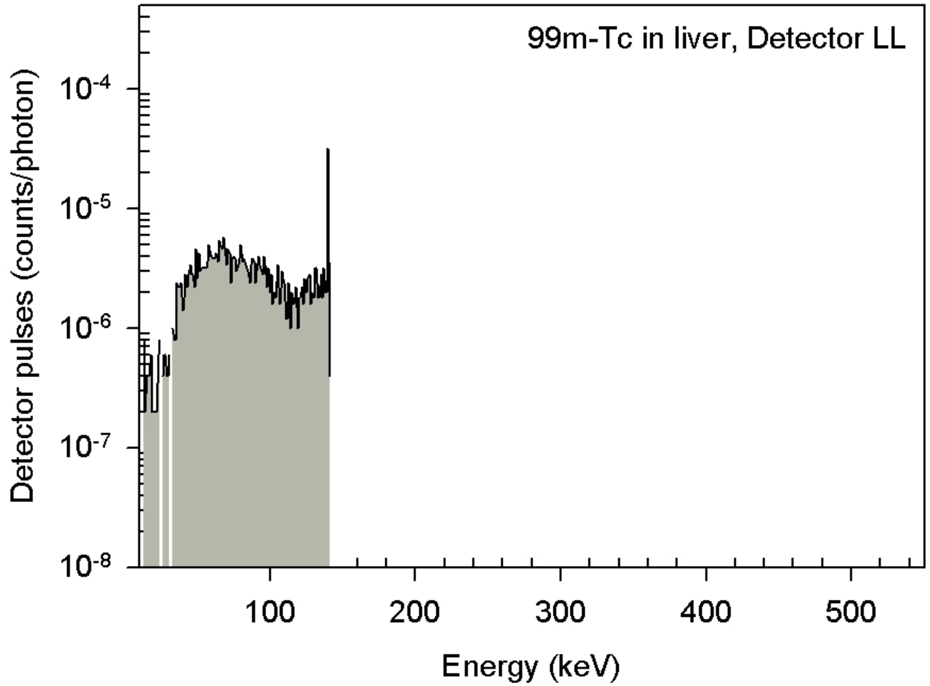
^{99m}Tc : ^{131}I = 50 : 50

Results and Discussion

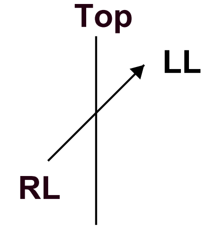
Spectral Signature – Micro Detective System with Voxel phantom



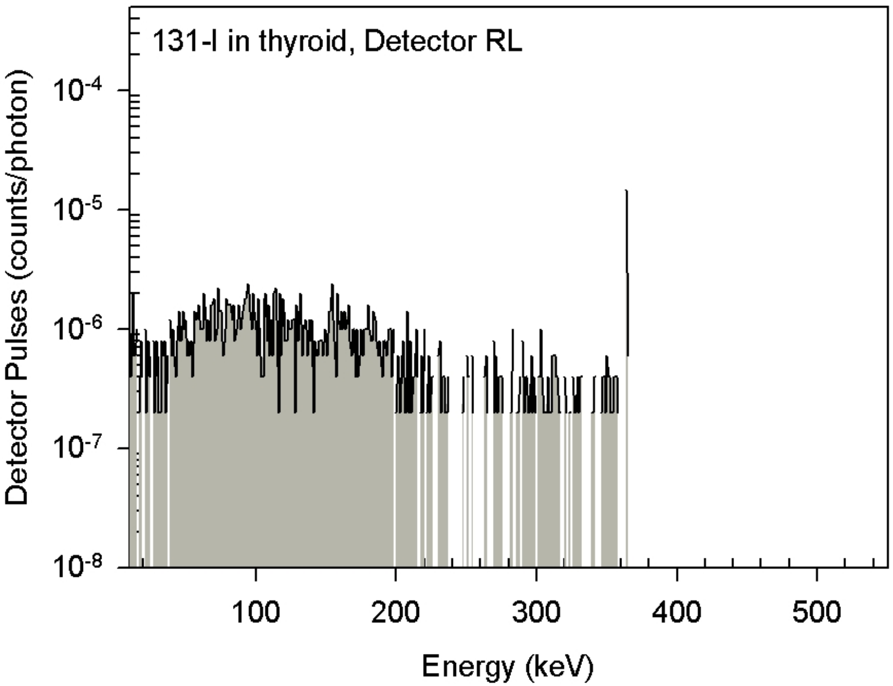


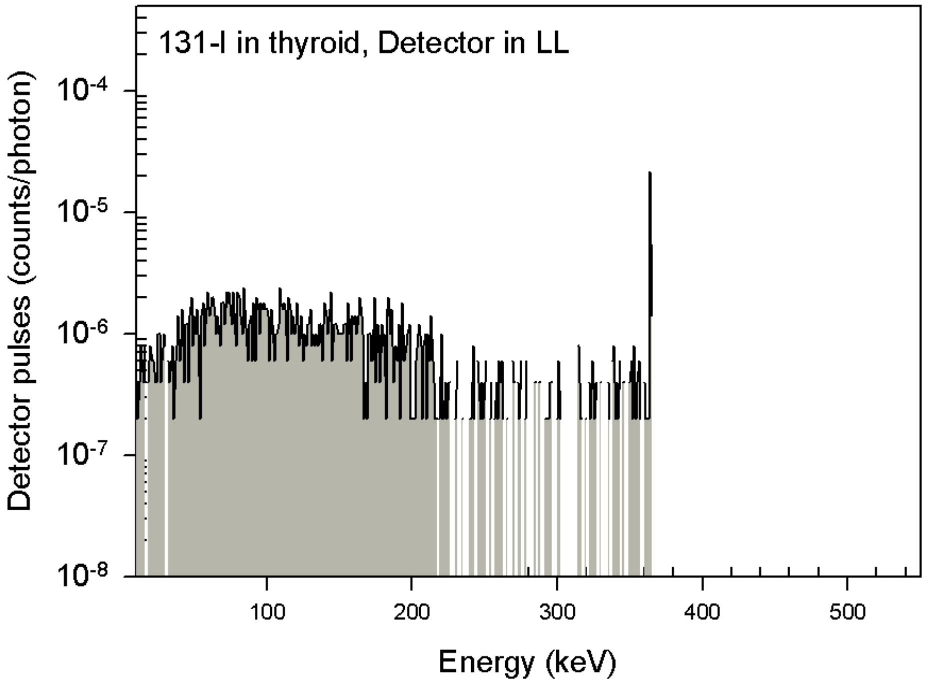


Spectral Signature – Micro Detective System with Voxel phantom



Voxel phantom





Conclusion

Micro Detective Performance

□ The Monte Carlo tool described in this presentation establish its ability of generating the characteristic spectral signatures for medical radio nuclides; - distributed in the attenuating medium or human body, as captured externally in radiation detectors

- The MicDet showed a significant difference in its detection efficiency over a range of 50 to 550 keV energy

- MicDet showed higher efficiency to detect 140 keV photons (emitted from ^{99m}Tc), in comparison to that for 364 keV (^{131}I) for a given source to detector distance.

Conclusion

Micro Detective Performance

- **During security screening, a detector with high efficiency is effective to stop someone, carrying a radionuclide in the body before the person reaches the security point. MicDet is less efficient (unable to detect signal), beyond 5 to 6 m distance.**
- **The characteristic signatures captured in the MicDet (HPGe) detectors for point sources embedded inside a multi-layer attenuating medium showed differences in the Compton tails, caused by different attenuating scheme.**

Conclusion

Micro Detective Performance

- Radio nuclides distributed over organs in an ICRP voxel phantom mimicked to physical distribution . A cross-check study will be performed by laboratory – Phantom studies
- In future studies, exotic radio nuclides, used for medical therapeutic purposes, e.g., bone, bone marrow, knee joint, will be studied.
- Inclusion of a voxel phantom generated from real human body and integrating the phantom with detection system will open further possibilities of studying medical radionuclide for therapeutic and diagnostic purposes

QUESTIONS ?