Commissioning of a PC cluster for the calculation of scanner-specific normalised organ doses from CT

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Introduction

NRPB-R249

Survey of CT Practice in the UK

Part 2: Dosimetric Aspects

P C Shrimpton, D G Jones, M C Hillier,
B F Wall, J C Le Heron and K Faulkner

NRPB

National Radiological Protection Board

NRPB-R249

NRPB-R248-250 (1991)

NRPB-SR250 (1993)

Introduction

CT scanners

- X-ray source: tube voltage, anode angle, filtration and ripple
- Geometry of CT scanners, including collimation
- Rotating beam: thickness, fan angle
- Bow tie filter
- Normalisation of X-ray output in measurable CTDI

After 1990s

- Multi (64) slice CT scanners
- Dual source CT scanners
- Increasing rotation speed, resolution, X-ray output
- Potential higher doses and risk

PC Cluster Hardware

PC Cluster

- 7 nodes each with
  - 2x Dual Core AMD Opteron processors
  - 8 GB of memory
  - Harddisk 250 GB (calculation nodes)
  - 750 GB RAID-5 (server node)
- ARC-1110 SATA RAID Controller (server node)
- Ethernet switch
- KVM switch

PC Cluster Software

Software

- AMD64 or Extended Memory 64 Technology (EM64T)

Operating system

- Linux Fedora Core 5 and 6

Radiation transport codes

- MCNPX2.5.0 (LANL) and
- MCNP5.1.40 (LANL)

Fortran 90/95 Compilers

- Intel Fortran 95 compiler 9.1.045 and
- Portland Group Inc. (PGI) Fortran 90/95 compiler 7.0-2

Portable Batch System

- OpenPBS 2.3.16

PC Cluster Software

Installation of MCNPX and MCNP5

- MCNPX PGI compiler option –fastsse results in internal break down
- Binary cross section data libraries are compiler dependent

Calculation speed

- Including electron transport is about 2 orders of magnitude slower than photon only transport in a mathematical phantom
- Voxel phantoms are about 1 order of magnitude slower than mathematical phantoms
- MCNP5 PGI compiler option –fastsse results sometimes in faster sometimes in slower code
- Uncertainty in run time can be in excess of 10%

PC Cluster Software

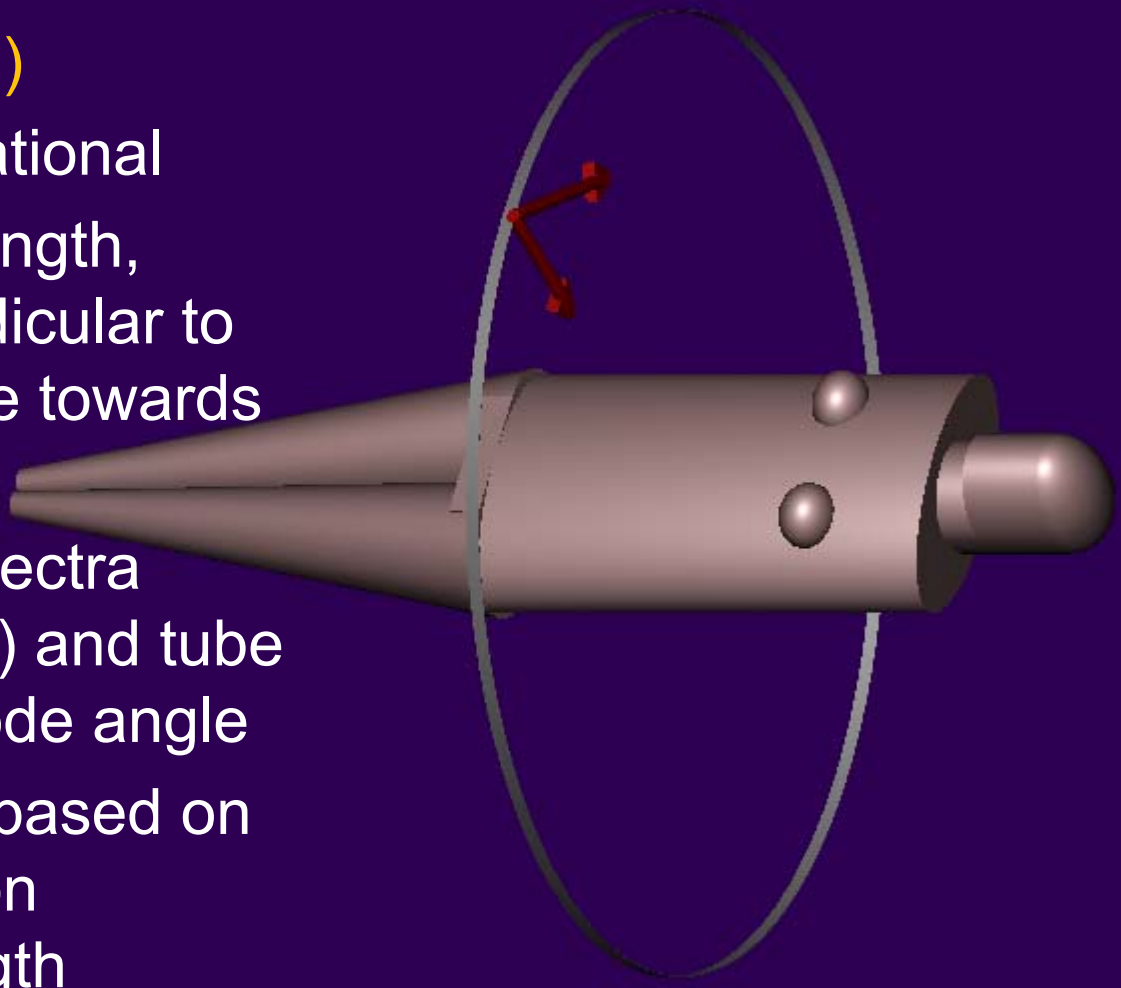
Calculation speed for GSF-Golem in AP direction (nps 10^7)

MCNP Code	F90/F95 compiler	Option optimise	Set-up time min	Run time min	Post-process time min
MCNPX	Intel		0.84 ± 0.04	141 ± 12	0.02 ± 0.01
MCNPX	PGI		0.98 ± 0.01	166.4 ± 0.7	0.00 ± 0.01
MCNP5	Intel		909 ± 52	119 ± 13	0.02 ± 0.01
MCNP5	PGI	fastsse	1621 ± 16	133 ± 6	0.01 ± 0.01

CT Scanner Source Definition

NRPB-SR250 (David Jones)

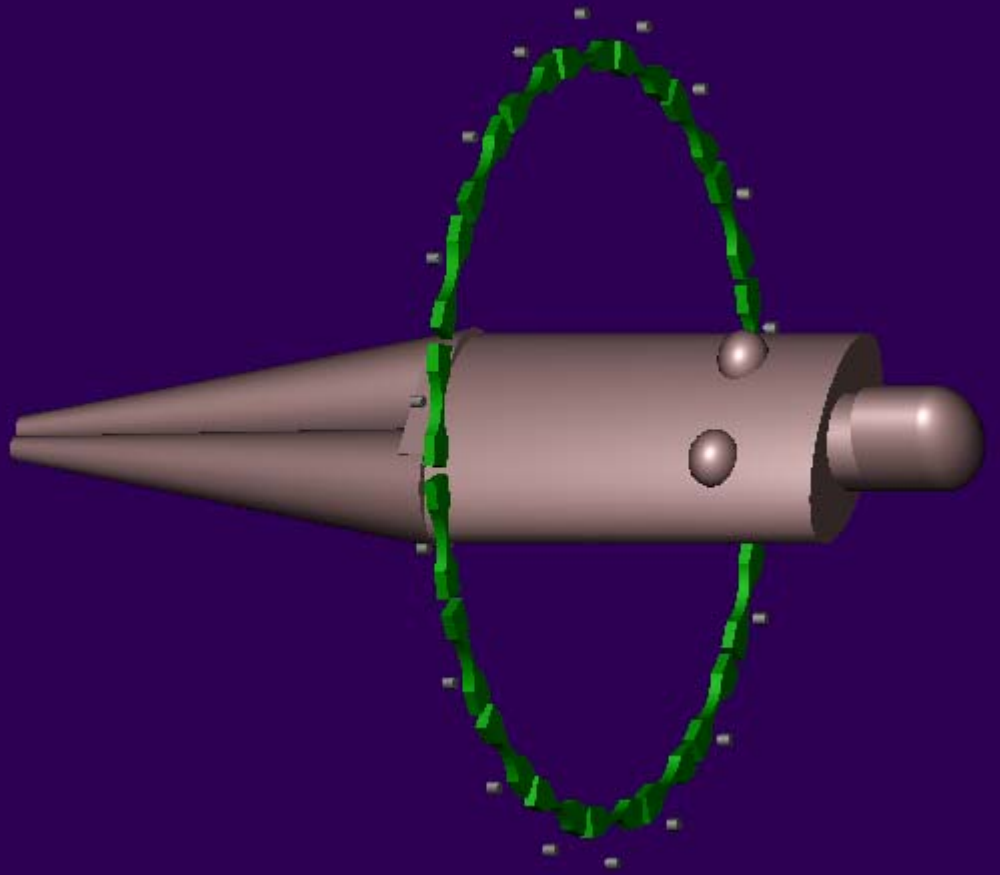
- Source is continuous rotational
- Line sources of 0.5 cm length, emitting photons perpendicular to the line and in a fan angle towards centre of rotation (COR)
- Photon energy is from spectra based on W.J. Iles (1987) and tube voltage, filtration and anode angle
- Bow tie filter attenuation based on material, mass attenuation coefficients and path length
- Monte Carlo program is home-made



CT Scanner Source Definition

Amjad Khursheed

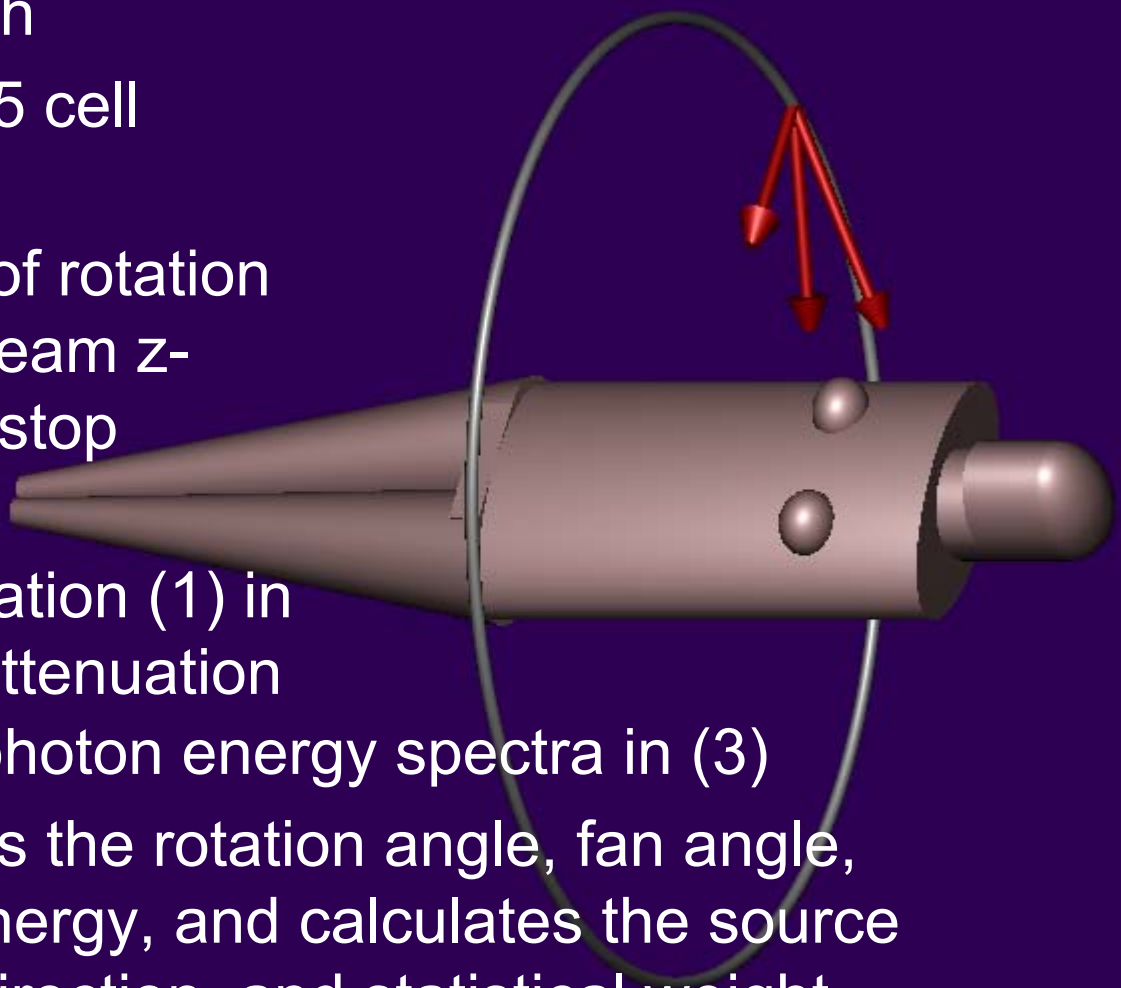
- Line sources are placed at 72 or 18 discreet positions.
- Line sources of 1 cm length, emitting photons perpendicular to the line over the full fan angle
- Photon energy based on IPEM-78 (1997)
- Bow tie filter is implemented at 18 different places matching the 18 source positions
- Monte Carlo program is MCNP4C



CT Scanner Source Definition

MCNP using the source subroutine

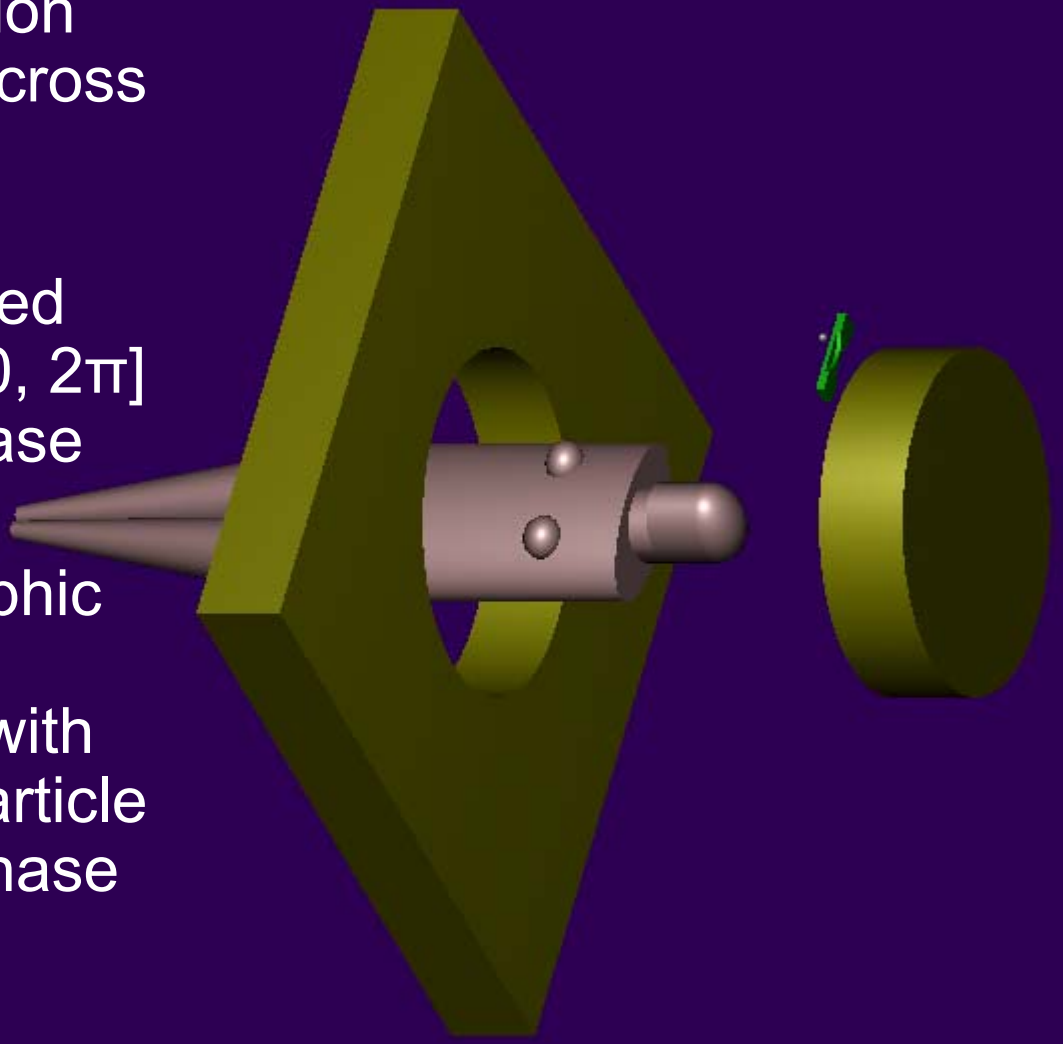
- User supplied input through
  - idum: particle type and 5 cell numbers
  - rdum: source to centre of rotation distance (cm), central beam z-position (cm), start and stop rotational angle (rad)
  - distributions: fan attenuation (1) in COR plane, thickness attenuation (2) in COR plane, and photon energy spectra in (3)
- Subroutine source samples the rotation angle, fan angle, thickness angle, photon energy, and calculates the source particle starting position, direction, and statistical weight



CT Scanner Source Definition

MCNP using the phase space file

- CT scanner at a fixed position and write the particles that cross the cylinder.
- Rotate the position and direction of an angle sampled homogeneously between [0, 2π] and write to the second phase space file
- Calculate the anthropomorphic organ doses or CTDI in a second MCNP calculation with the cylinder as a starting particle position from the second phase space file

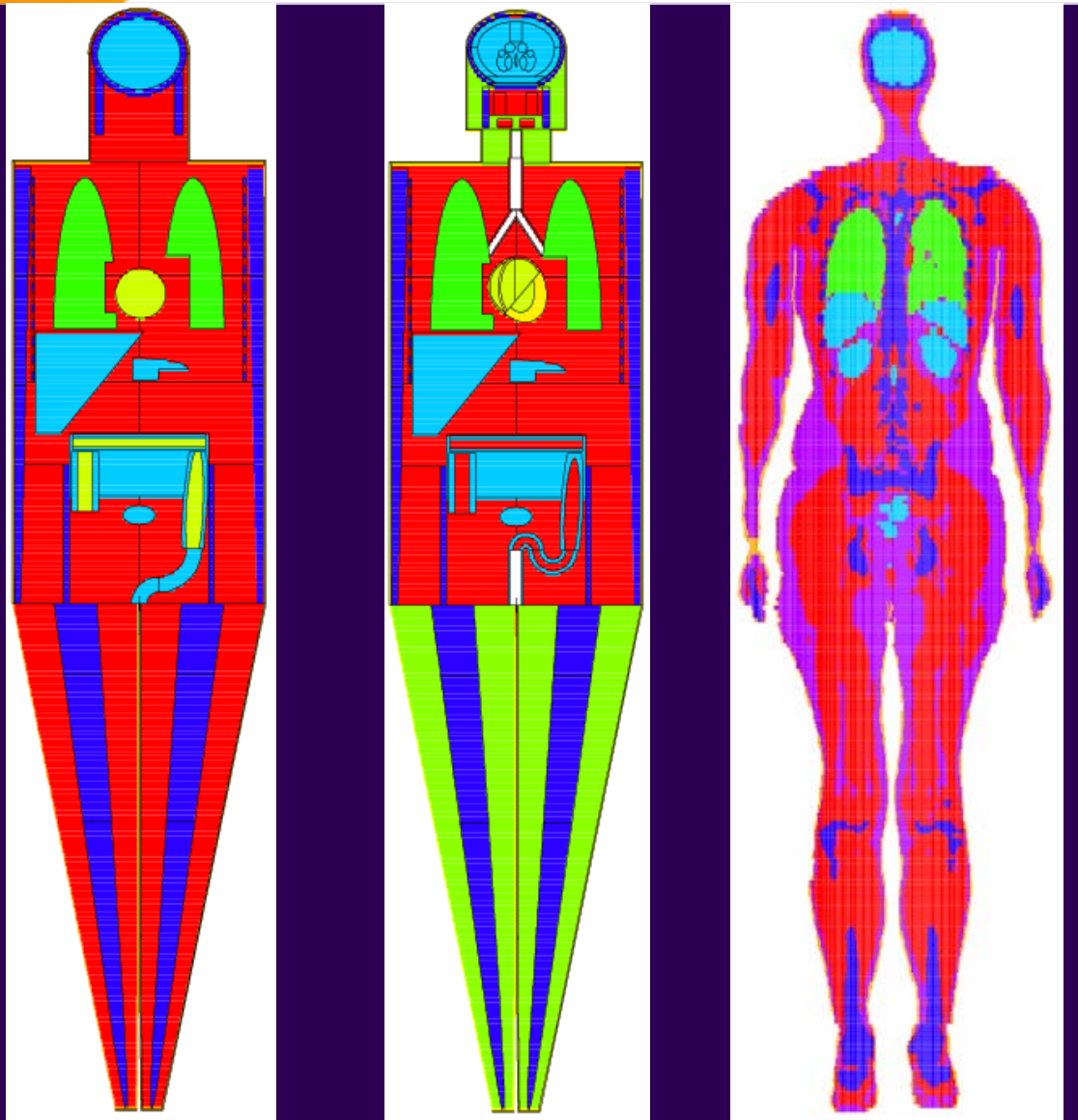


Example – Various Phantoms

Cristy and Eckerman based NRPB18+

Revised ORNL phantom HPA18+

Voxel (256 x 256 x 220 or 2.08 mm x 2.08 mm x 8 mm) based phantom GSF-Golem (Zankl)



Anthropomorphic Phantoms

Anthropomorphic mathematical phantoms

- Cristy adult hermaphrodite phantom (NRPB-SR250)
  - Breast composition 50:50 mixture fat water
  - Neck incorporated
  - Bone marrow and bone surface dose calculation
- Cristy and Eckerman phantom (NRPB18+)
  - Simplified thyroid and heart
  - GSF based neck and oesophagus
  - Bone marrow and bone surface dose calculation
- Revised NRPB18+ phantom (HPA18+)
  - Modified according to more recent publications

Anthropomorphic voxel phantoms

- GSF Golem

Quality Assurance – Comparing SR250 & MCNPX Results

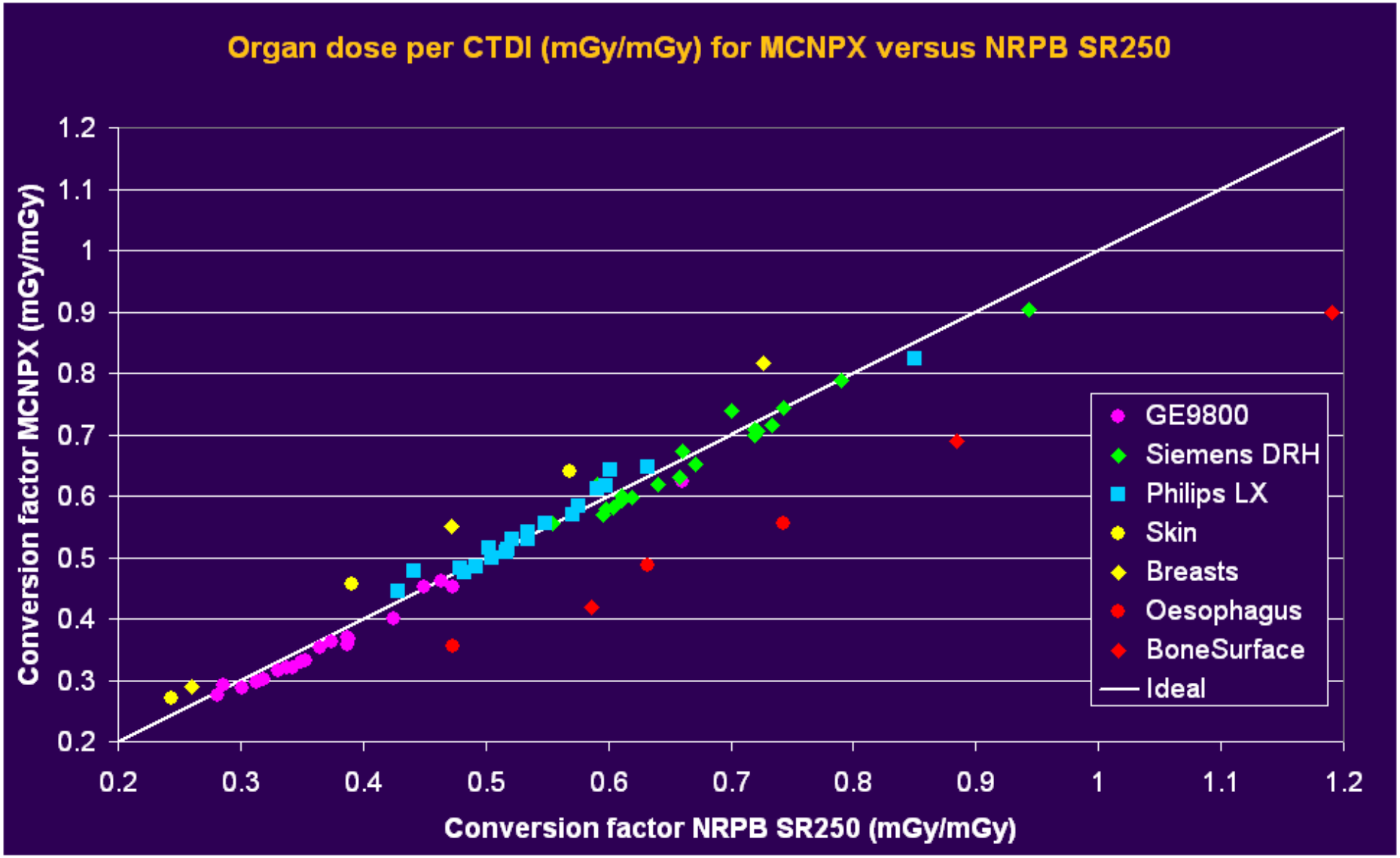
Three scanners

- General Electric 9800
- Siemens DRH
- Philips LX

Comparison of the three scanners

- High consistency between old and new calculations
  - Normalised organ doses (D_{Organ} / $CTDI_{Free\text{-}in\text{-}air}$) for various organs
  - Highlighting organs with more than 10% difference
  - Highlighting organs with more than 30% difference

Quality Assurance – Comparing SR250 & MCNPX Results



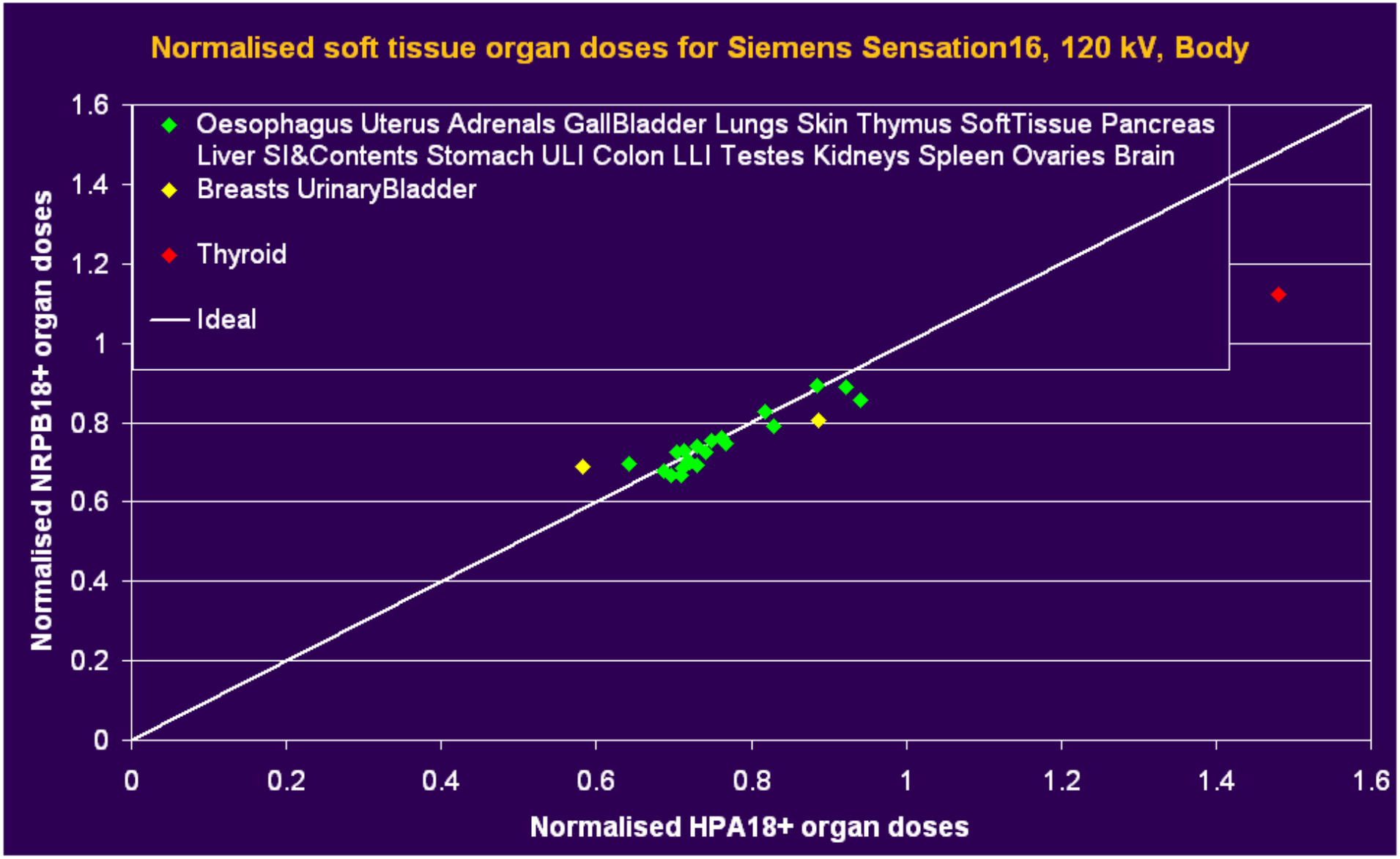
Quality Assurance – Comparing SR250 & MCNPX Results

Comparing various calculation techniques for the Philips LX

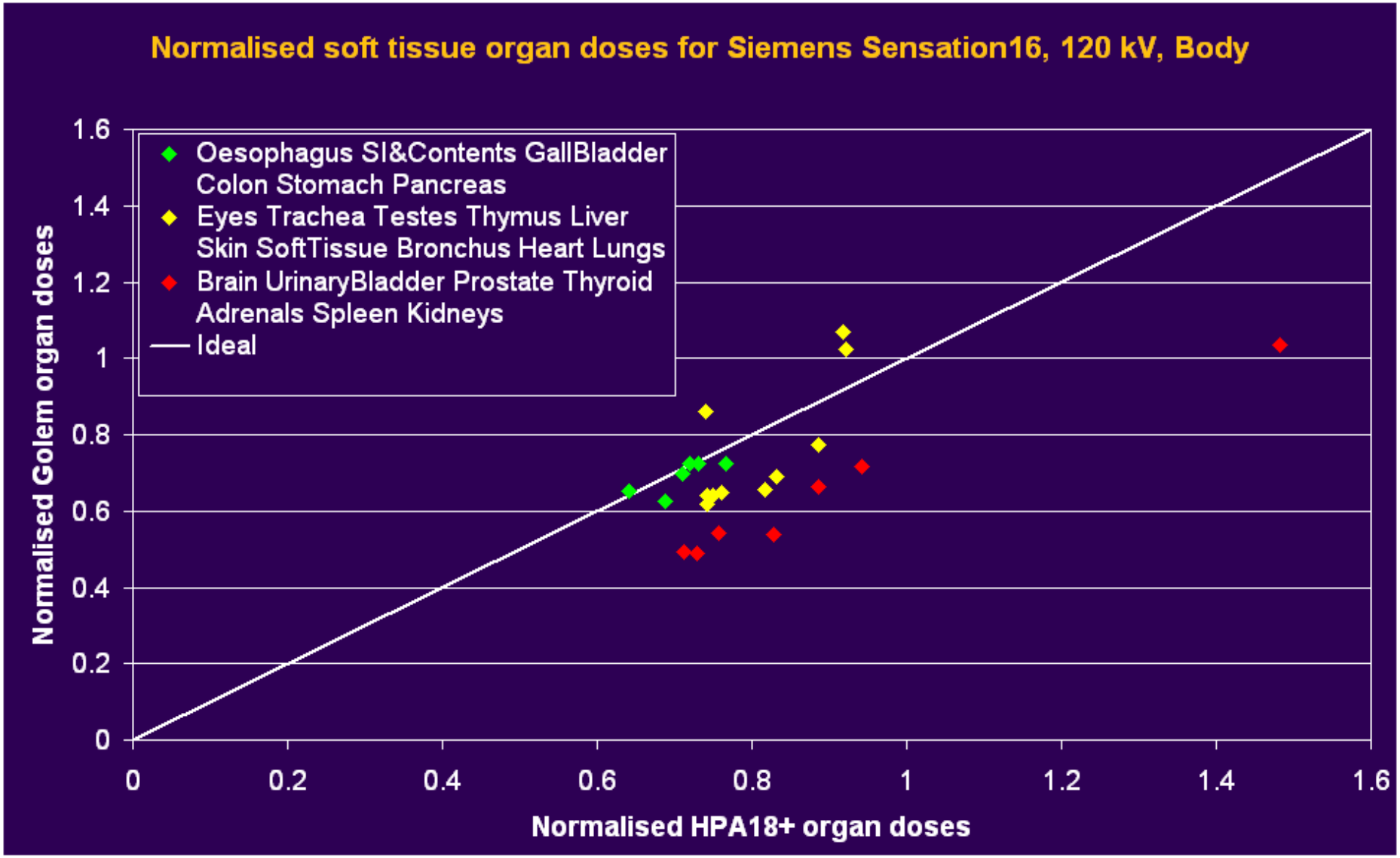
Table with ratios of normalised organ doses for all slices for various different calculation methods

Source	Rotation	Bone Dose	Min	Max	$E_{ICRP-60}$
Line	Continuous	ORNL	1	1	1
Line	Continuous	NRPB	0.43 BS 0.90 BM	1	0.97
Line	Discrete	ORNL	0.98	1.03	1.00
Point	Continuous	ORNL	1.02	1.05	1.03

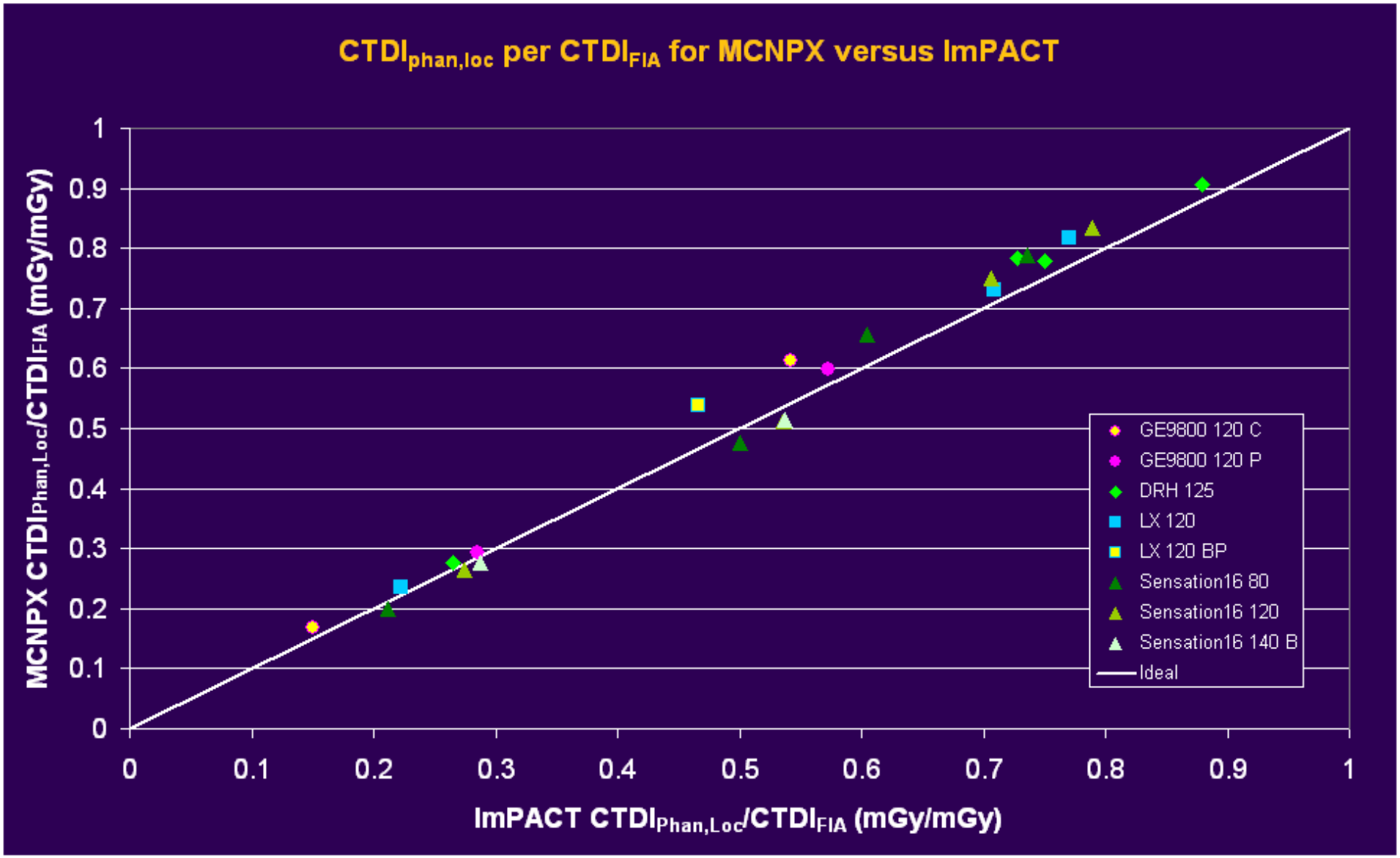
Anthropomorphic Phantoms



Anthropomorphic Phantoms



CT Scanners – CTDI Phantom



Contemporary CT Scanners – Siemens Sensation 16

Effective dose per $CTDI_{FIA}$ calculated with MCNPX & ImPACT

Tube voltage (kV)	Examination	$E/CTDI_{FIA}$ ICRP-60 +RR +MWR -MWC MCNPX (mSv/mGy)	Match ImPACT (mSv/mGy)	RR Organ
80	Head	0.020	0.021	Brain
120	Head	0.027	0.022	Brain
80	Chest	0.15	0.17	Thymus
120	Chest	0.19	0.19	Thymus
140	Chest	0.20	0.23	Thymus
80	Abdomen	0.12	0.12	Kidneys
120	Abdomen	0.15	0.14	Kidneys
140	Abdomen	0.16	0.17	Kidneys
80	Pelvis	0.13	0.14	
120	Pelvis	0.17	0.17	
140	Pelvis	0.18	0.19	

Contemporary CT Scanners – Siemens Sensation 16, 120 kV

Effective dose per $CTDI_{FIA}$ calculated using ICRP 103 for various phantoms using surrogate organs

Examination	Program	Effective dose / $CTDI_{FIA}$ (mSv/mGy)			
ICRP		60+RR	103	103	103
Phantom		NRPB18+	NRPB18+	HPA18+	Golem
Head	MCNPX	0.027	0.030	0.033	0.019
Head	SR250	0.022	0.024		
Chest	MCNPX	0.19	0.22	0.21	0.26
Chest	SR250	0.18	0.22		
Abdomen	MCNPX	0.15	0.17	0.18	0.15
Abdomen	SR250	0.14	0.17		
Pelvis	MCNPX	0.17	0.13	0.13	0.07
Pelvis	SR250	0.17	0.12		

Future – Where Next

Available in the near future

- ICRP standard anthropomorphic voxel phantoms
- Manufacturer CT scanner information

Needed but probably not available until the distant (?) future

- User access to tube current data

Conclusions - Summary

- The PC cluster is ready to perform calculations!
- Huge difference in calculation time between different methods
- Significant difference in calculation time between MCNP5 and MCNPX for voxel phantoms
- Difference in calculation time for different Intel and PGI Fortran compilers

Conclusions - Summary

- Preparation of new conversion factors is timely
- Organ dose conversion factors from MCNPX are within 10% of SR250 values (with known exceptions for 4 organs)
- Differences in source simulation (parallel line vs divergent point, and continuous vs discrete) are small (<5%)
- Changes in bone dosimetry from NRPB to ORNL could increase the red bone marrow dose by 10% and the bone surface dose by a factor of 2.3
- ImPACT match for Sensation 16 is a good approximation for E (ICRP 60) in sample examinations (mostly <10%)
- ICRP 103 recommendations (implemented with and without surrogate organs) result in larger differences in E (up to 30%)

Thank you for your attention