Son of NRPB-SR250

New Monte Carlo calculations at HPA-RPD for contemporary CT

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History – Where we are …
Who is Jan Jansen?

Health Protection Agency

Expertise in Monte Carlo calculations with MCNP

- Dose conversion factors for: diagnostic radiology, screening mammography and CT
- Equivalent copper thickness of patient equivalent phantoms in terms of attenuation
- Determination of mean glandular tissue fraction
- Carcinogenic risk of radiotherapy for benign diseases

History – Where we are …
NRPB Reports

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)

History – Where we are …
NRPB-SR250

NRPB-SR250 (1993)

- 23 series of Monte Carlo calculations for 27 scanner models
- 208 sets (5 mm slabs) of normalised dose data for …
- 27 organs or regions of a mathematical phantom

More user-friendly access of data files

- Program to read the data files by J.C. Le Heron. CTDOSE: a user's guide. Software and manual. (National Radiation Laboratory, New Zealand (1993) (No longer available)
- ImPACT CT Patient Dosimetry Calculator Spreadsheet (2000-2006)
  - Matches scanners to the 23 Monte Carlo calculations

History – Where we are …
After NRPB-SR250

Work at the NRPB after SR250 by Amjad Khursheed

- Change of hardware from DEC-VAX to PC
- Change in operating system from VMS to MS-DOS / MS Windows (command-line window)
- Change in Monte Carlo code from home-made to MCNP4C
- Change in anthropomorphic phantoms from home-made MIRD compatible hermaphrodite adult to MCNP input based MIRD compatible hermaphrodite adult and newborn, 1, 5, 10 and 15 year olds
- Three scanners: GE 9800, Siemens Somatom DRH and Philips LX.

Changes – Why the Need?

Scanner

- Multi-slice scanners
- Spiral
- Tube current modulation or Automatic Exposure Control
- X-ray tube, computer speed and rotation time development

Patient model

- Voxel instead of mathematical phantoms
- Bone dosimetry
- Draft ICRP recommendations

Changes – Why the Need?

Monte Carlo calculation

- Software development from home-made to general codes
- Hardware from Workstation to PC Cluster

Dosimetry

- Increasing CT doses reported
- Paediatric CT examinations are increasing

Monte Carlo Calculations - Set-up

Computer Cluster

- 7 nodes each with
  - 2x Dual Core AMD Opteron processors
  - 8 GB of memory
- Ethernet switch
- KVM switch

Software

- Linux Fedora Core
- MCNPX and MCNP5 (LANL)
- Intel Fortran 95 compiler
- OpenPBS

Quality Assurance – Comparing SR250 & MCNPX Results

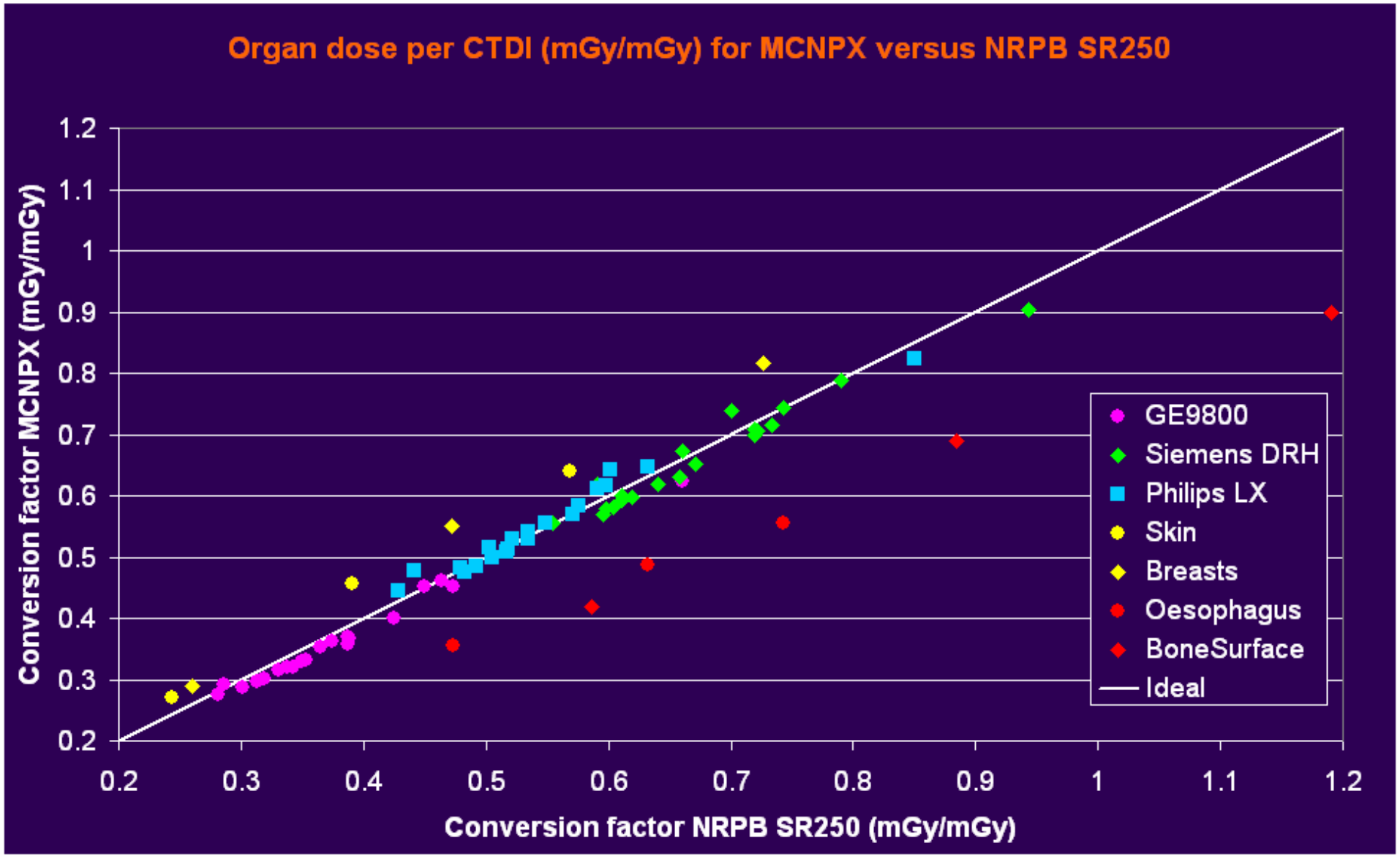
Three scanners

- 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	1	0.97
			0.90 BM		
Line	Discrete	ORNL	0.98	1.03	1.00
Point	Continuous	ORNL	1.02	1.05	1.03

Contemporary CT scanners – Example of the work

Information needed from CT manufacturers

Hardware

- Geometry
- Bow-tie filter, position, shape and material
- X-ray source description in tube voltage, filtration (thickness and material) and anode angle

Software (means of operation)

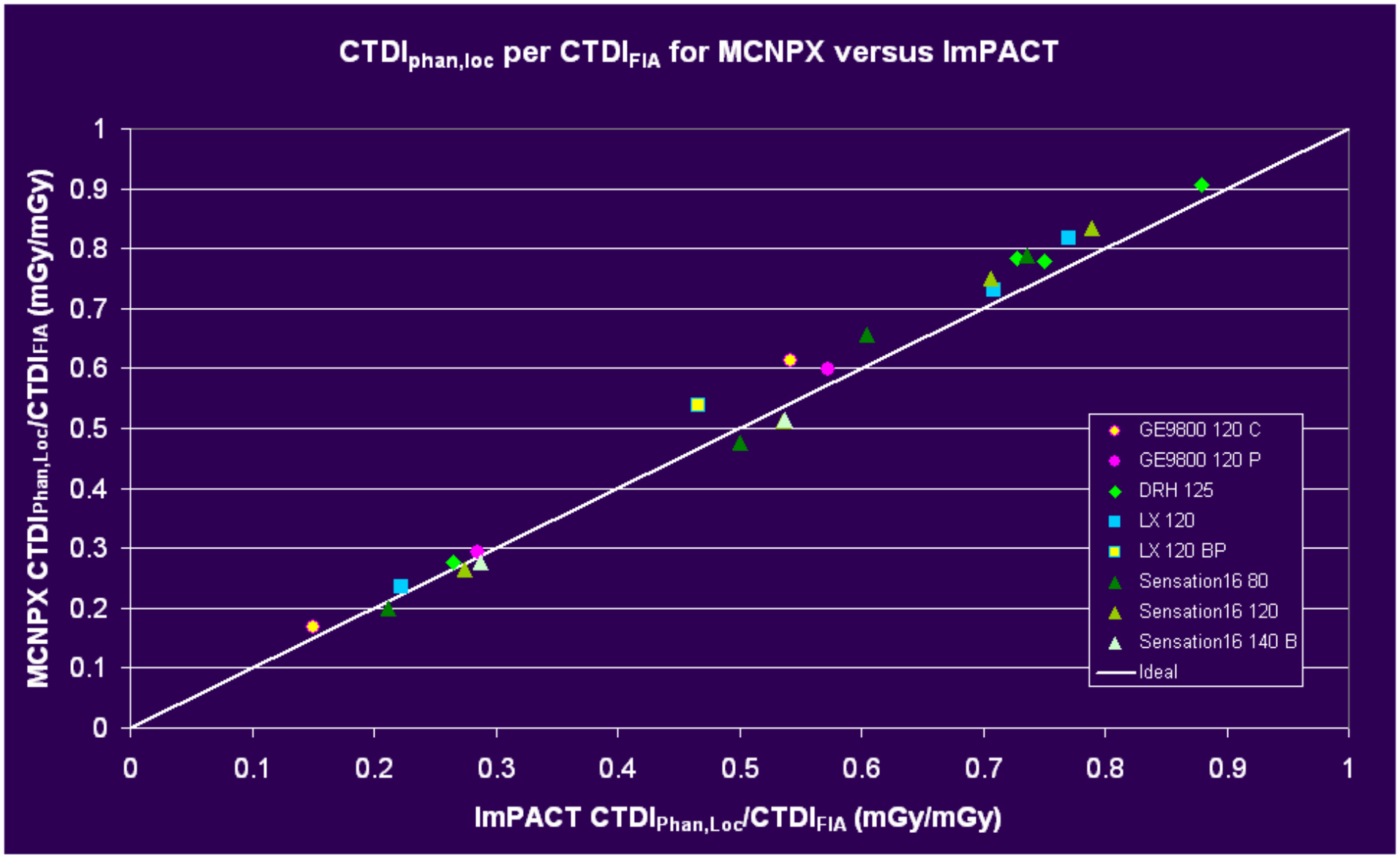
- Automatic exposure control
- Tube current modulation (minimum and maximum tube current)
- How to get user access to the tube current data?

Contemporary CT scanners – Example of the work

As an example, the Siemens Somatom Sensation 16

- Tube voltage: 80, 100, 120 and 140 kV
- Filtration: 3 mm Al + 1.2 mm Ti + 1.6 mm PTFE (Body)
  3 mm Al + 0.6 mm Ti + 1.6 mm PTFE (Head)
- Tube current: constant, AEC (function of z derived from topogram), tube current modulation (function of angle derived from previous half scan) and AEC and tube current modulation
- Collimation (mm): 1.2, 2, 9, 10, 12, 18 and 24 mm
- Pitch
- Scan area on the patient

Contemporary 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 – Sensation 16, 120 kV

Effective dose per $CTDI_{FIA}$ calculated with Remainder Rule and +/- Mass Weighed Remainder and Colon, and using new ICRP Draft

Examination	Program	Effective dose / $CTDI_{FIA}$ (mSv/mGy)			
MWR		-	+	+	Draft†
MWC		-	-	+	
Head	MCNPX	0.027	0.027	0.027	0.034
Head	SR250	0.022	0.022	0.022	0.028
Chest	MCNPX	0.19	0.19	0.19	0.21
Chest	SR250	0.18	0.18	0.18	0.21
Abdomen	MCNPX	0.15	0.15	0.17	0.15
Abdomen	SR250	0.15	0.14	0.16	0.15
Pelvis	MCNPX	0.17	0.17	0.16	0.14
Pelvis	SR250	0.17	0.17	0.15	0.13

† With surrogate organs

Future – Where we go

Available in the near future

- ICRP standard anthropomorphic voxel phantoms
- Draft ICRP recommendations for effective dose
- 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!
- 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%)
- Draft ICRP recommendations (implemented with surrogate organs) result in larger differences in E (up to 30%)