ImPACT

Imaging Performance Assessment of CT Scanners

*A Medical Devices Agency Evaluation Group*

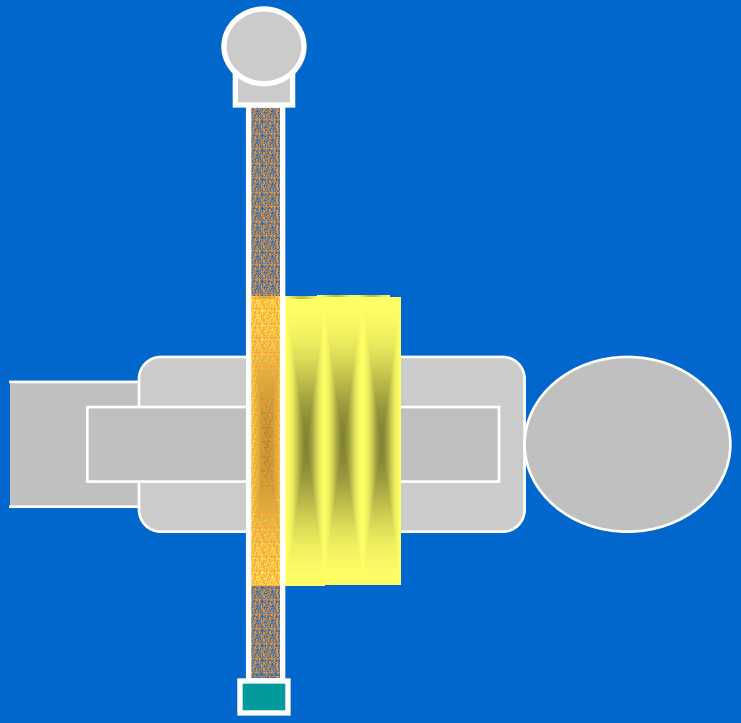
MDA MEDICAL DEVICES AGENCY

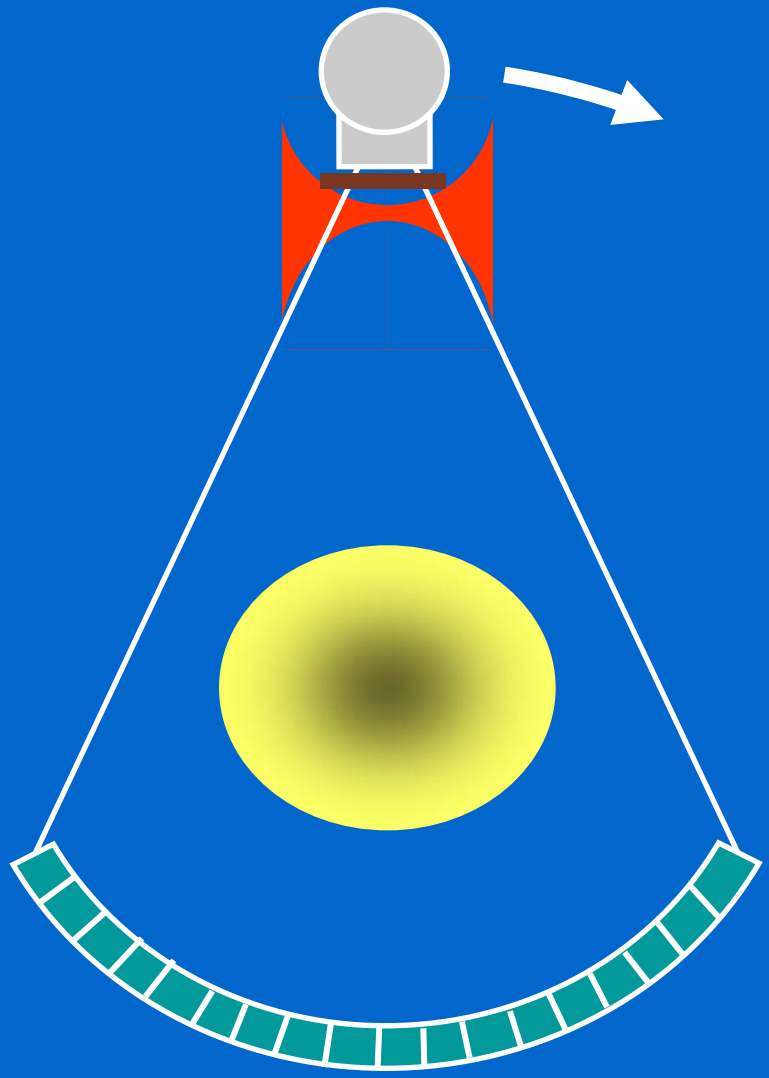
# CT dosimetry and a data base for CTDI values

## EFOMP Workshop at ECR 2002

S. Edyvean, ImPACT
St George's Hospital,
London

# CT scanner dose distribution





higher

lower

# CT scanner dosimetry

- Computed Tomography Dose Index (CTDI)
  - $CTDI_{FDA}$
  - $CTDI_{100}$
  - $CTDI_{w}$

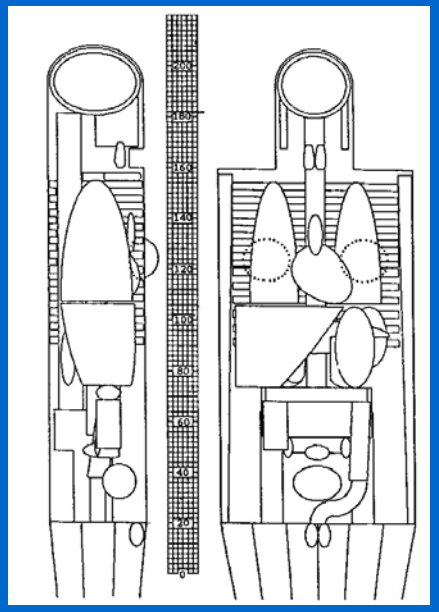
$$CTDI_{100} = \frac{1}{T}\int_{-50}^{+50} D(z)dz$$

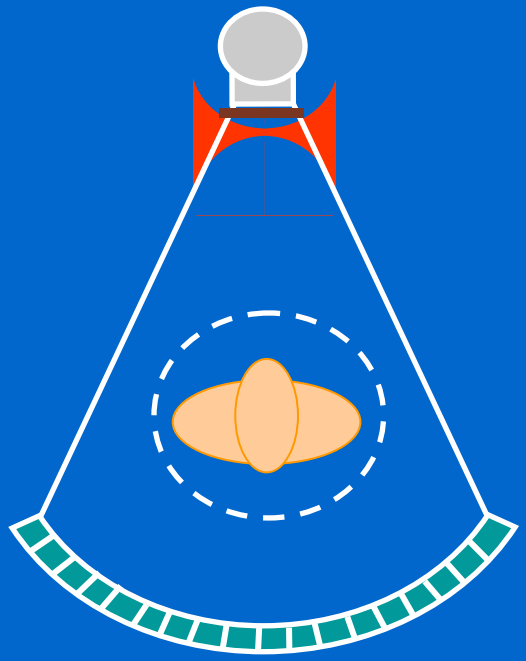
$$CTDI_{w} = 1/3 CTDI_{c} + 2/3 CTDI_{p}$$

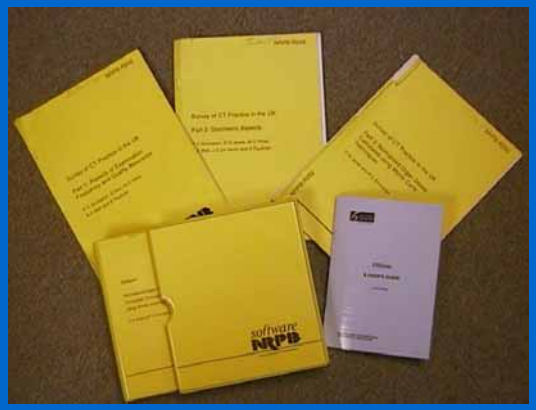
c = centre positon, p= periphery position

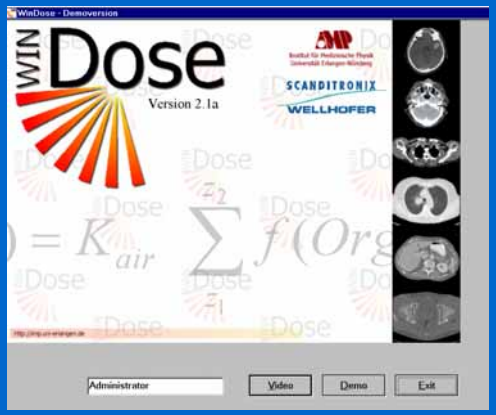
# CT scanner dosimetry

- Monte Carlo Calculations
  - NRPB (1991,1993)
  - GSF (1991)
  - WinDose



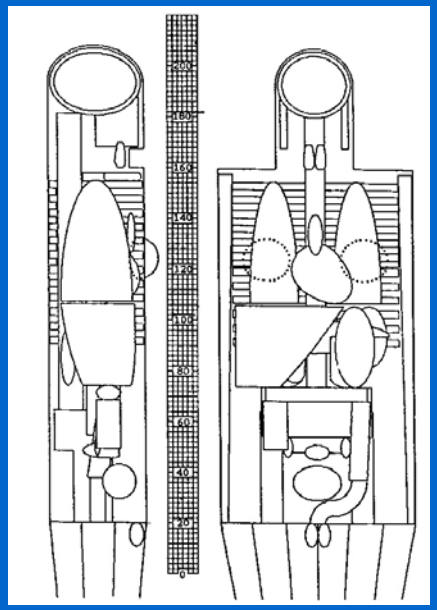




# NRPB CT organ dose datasets

- NRPB SR250, 1993
- 23 Organ dose data sets generated using MC calculations
  → Effective Dose
- Organ dose and ED expressed relative to CTDI in air
  → $_{n}D$ mGy / mGy, $_{n}ED$ mSv/ mGy
- Numerical phantom

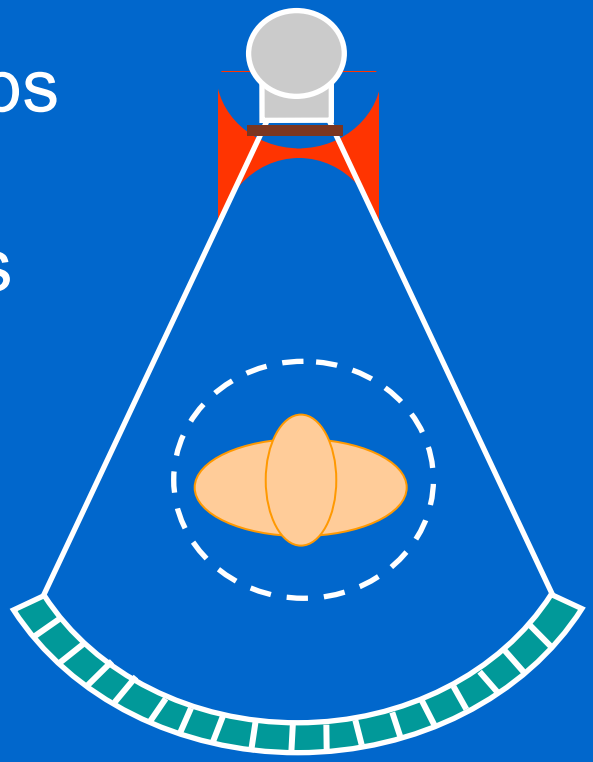



NRPB R248 , 249, 250, SR250

# NRPB CT organ dose datasets

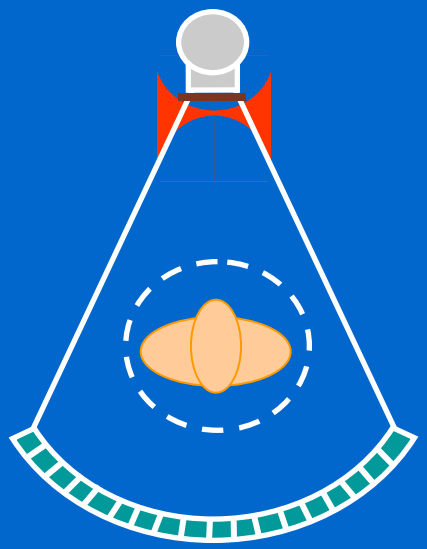
- Relevant information from manufacturers for 27 scanner models
- Condensed to 13 scanner groups based on scanners with similar dosimetry characteristics
- Different kVs

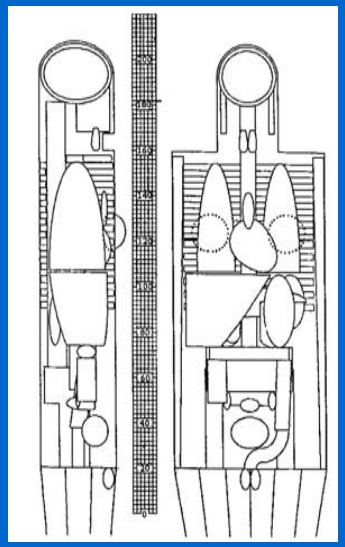
  ➔ 23 Monte Carlo organ dose data sets



# Purpose of ImPACT survey

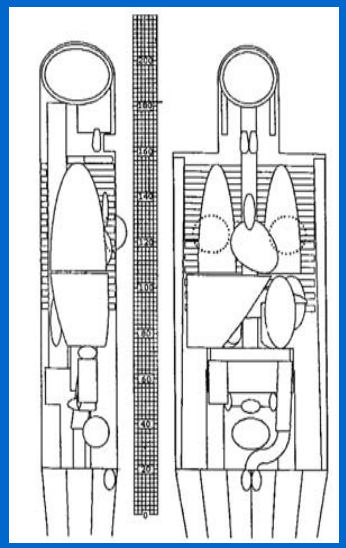
- In 1996  80 scanner models with different names in use in the UK
- NRPB SR250 MC data sets not applicable to ~65% of scanners in UK
- increasing due to number of newer scanner models
- How to estimate patient doses on these scanners ?

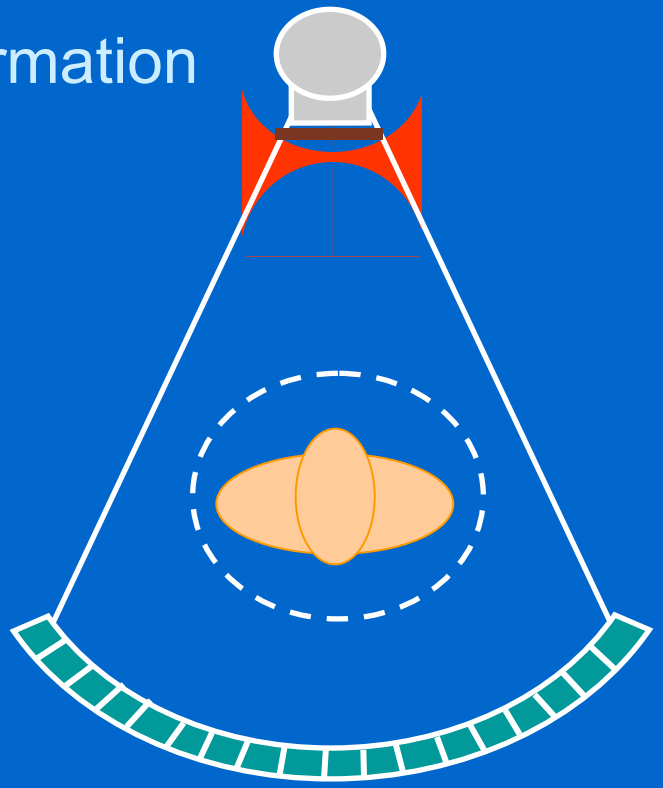




# Three choices

1. Generate new MC datasets
   - no relevant expertise
   - difficult to acquire accurate information on ~ 80 scanner models



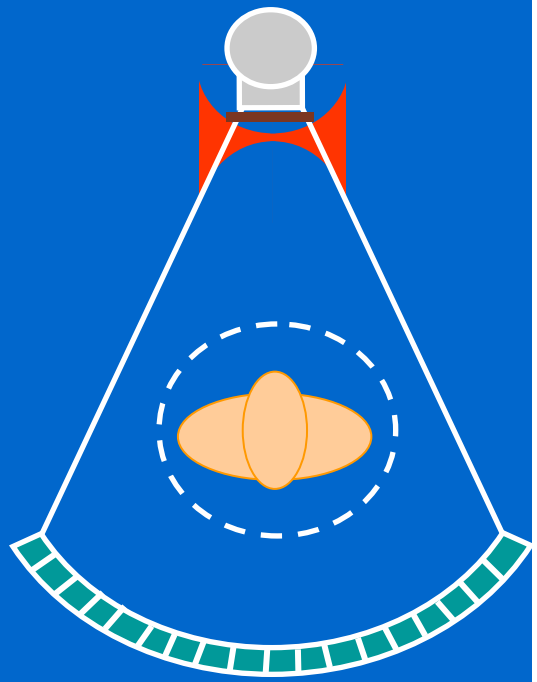


# Three choices

2. Data set from an ‘average’ scanner
   - does not address differences between models

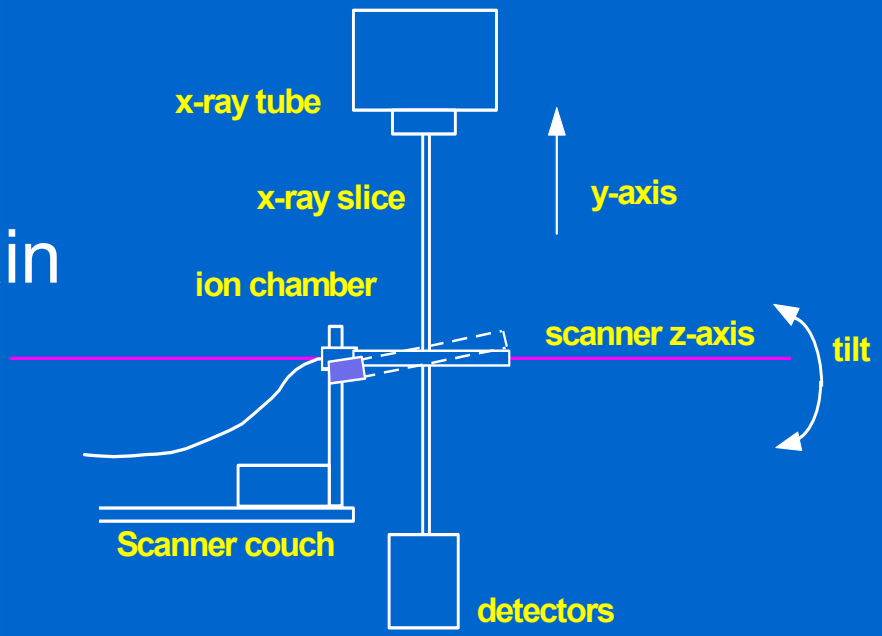
3. Use dose distribution characteristics to match new scanner models to those used in NRPB SR250

   Then use appropriate MC data set
   - Based on assumption that old and new scanners fell within similar ranges
   - method chosen



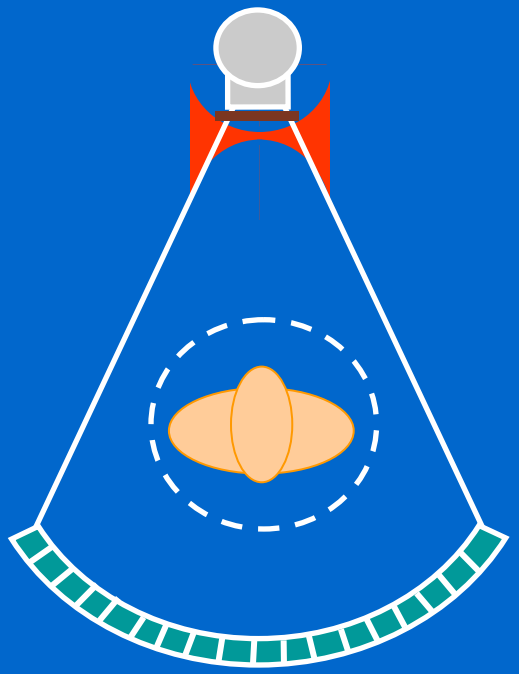
# Scanner Characteristics Survey

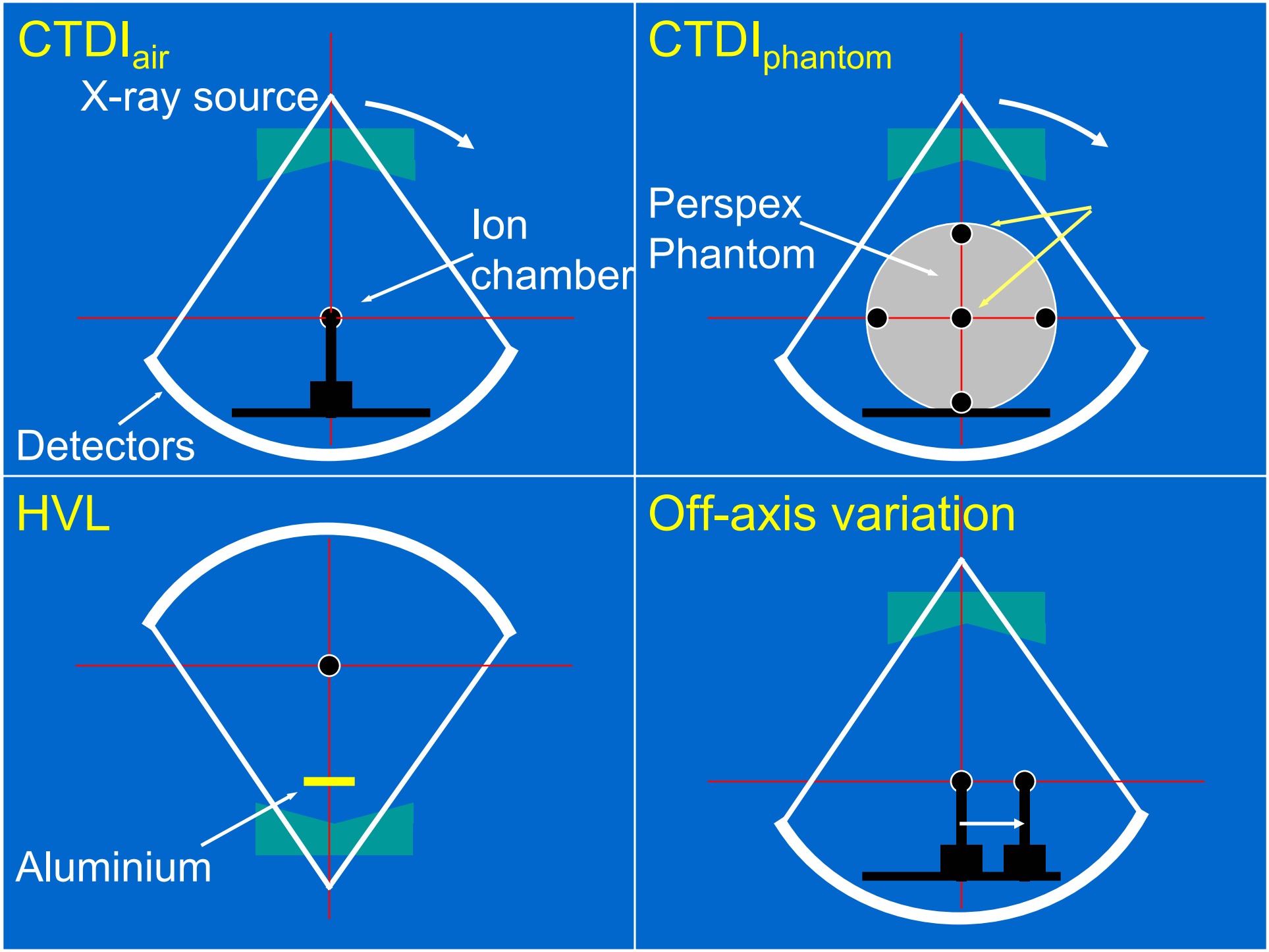
- Measurement based approach
  - easy to carry out on existing and future scanners
- Standard protocol
  - how to do the measurements
  - accuracy and tolerances of set up
  - data sheets
- 30 centres, 74 scanners
- UK + Holland,France,Spain



# Scanner models

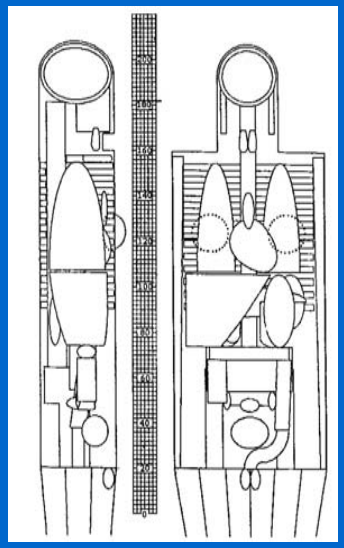
- 80 models ➔ ~ 40 groups
  - at first by partial knowledge
  - then refined by review of measurement data

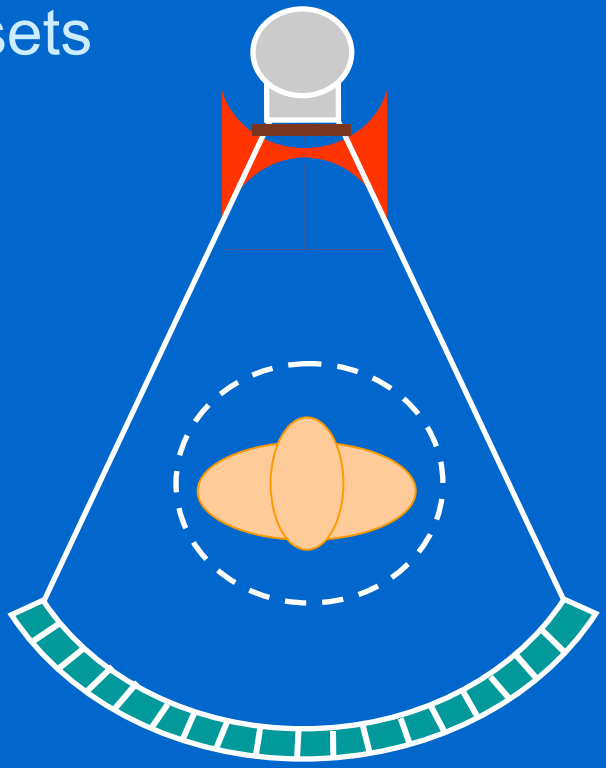



CTDIair
X-ray source
Ion chamber
Detectors
CTDIphantom
Perspex Phantom
HVL
Aluminium
Off-axis variation

# ImPACT survey data

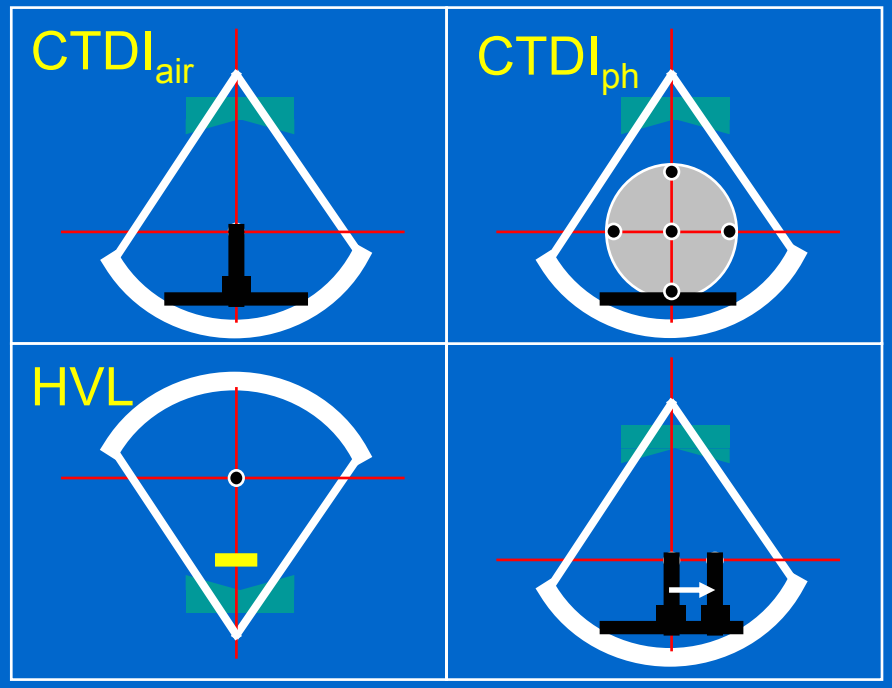
- Separated scanners into
  - those with NRPB SR250 MC data sets
  - newer models without

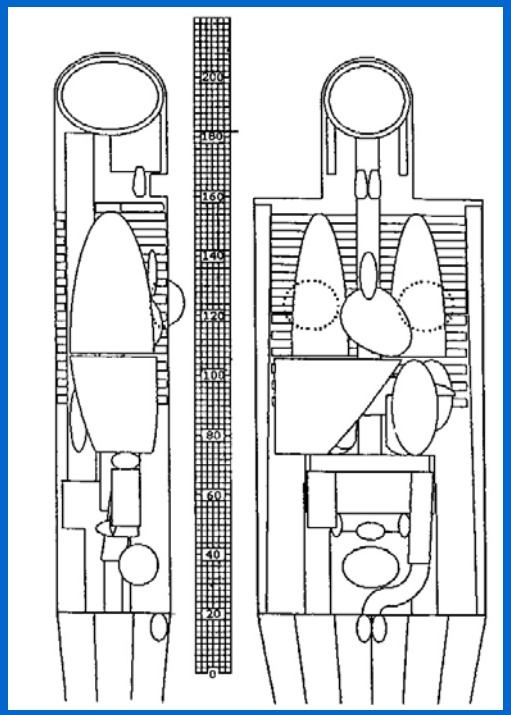





# Scanners with NRPB SR250 MC data sets

- Survey measurement data versus calculated ED
- Establish which combination of data gave best correlation



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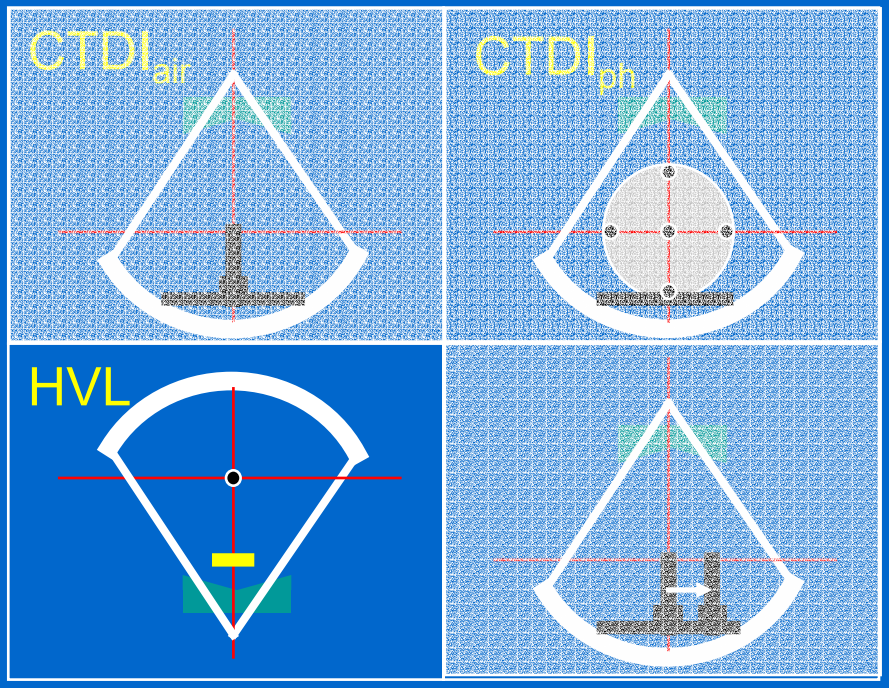
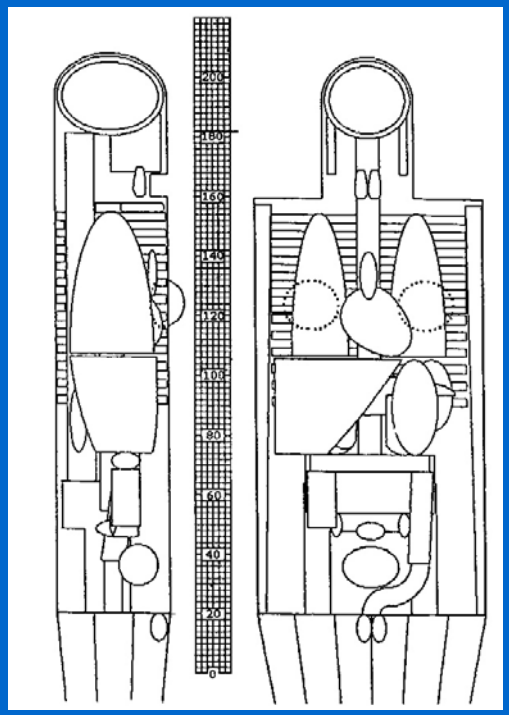
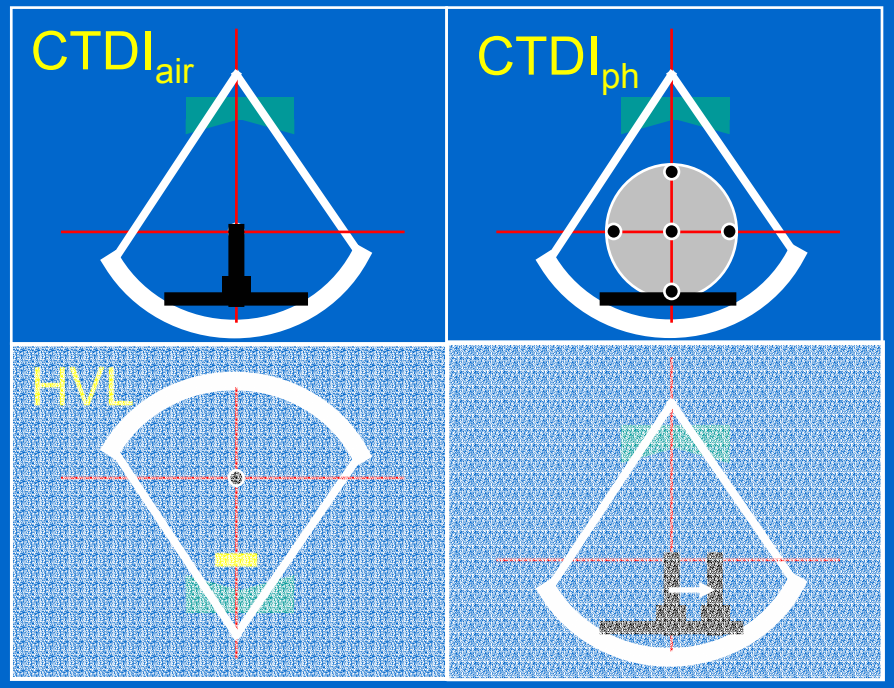
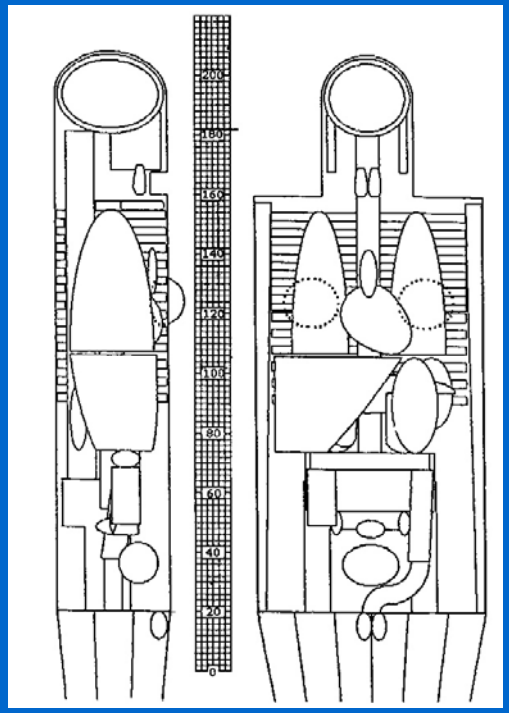


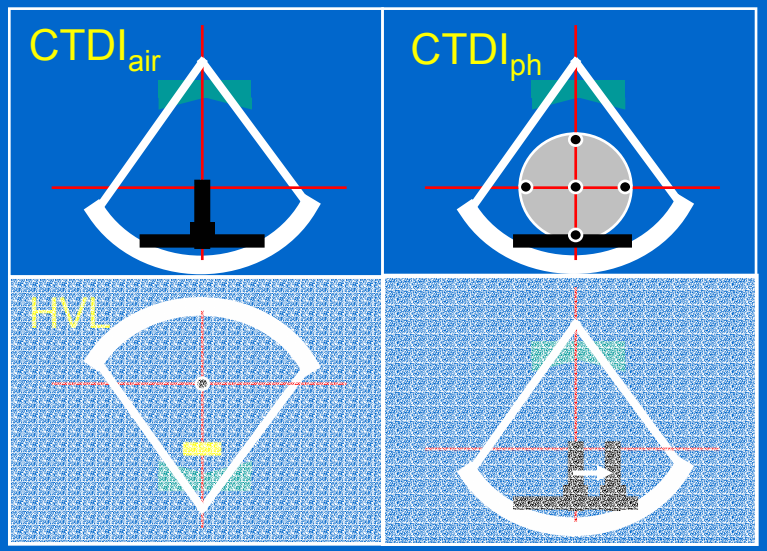
# Scanners with NRPB SR250 MC data sets

- Survey measurement data versus calculated ED
- Establish which combination of data gave best correlation with ED



# CTDI data : phantom factor

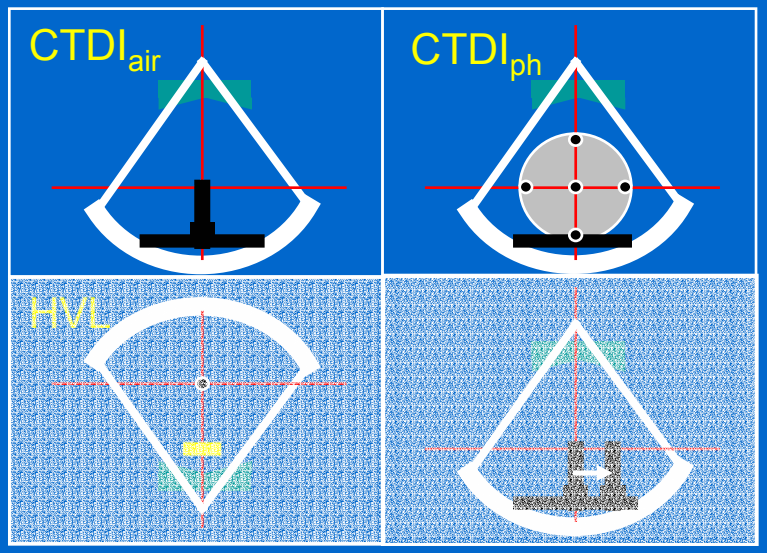



Phantom Factor = $CTDI_w$ / $CTDI_{air}$

Gelijns, K.
Patient Dosimetry in Diagnostic Radiology, Chest Examinations and Computed Tomography, PhD Thesis, Leiden

# ‘ImPACT’ factor

$CTDI_{air}$

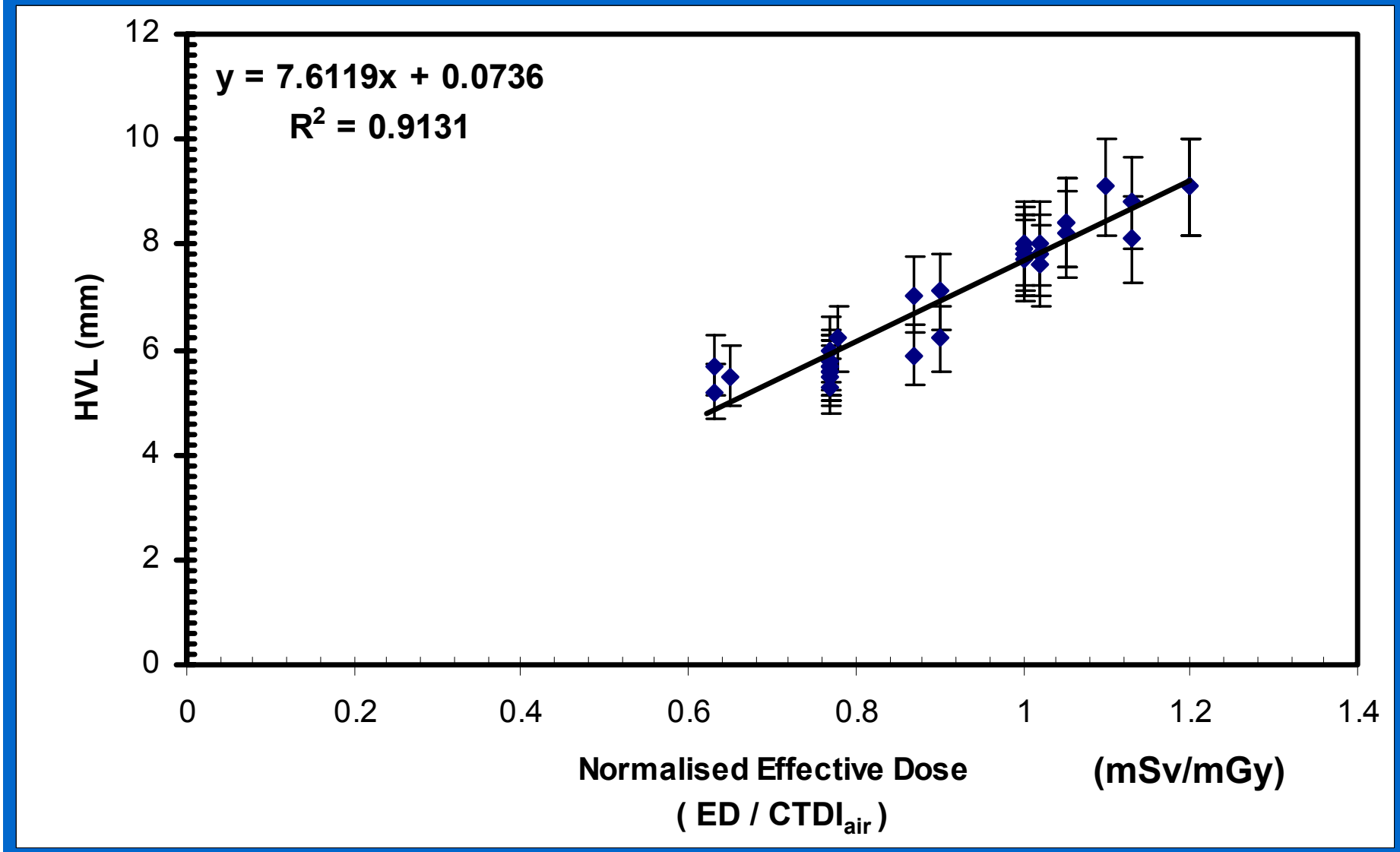



$CTDI_c$,$CTDI_p$

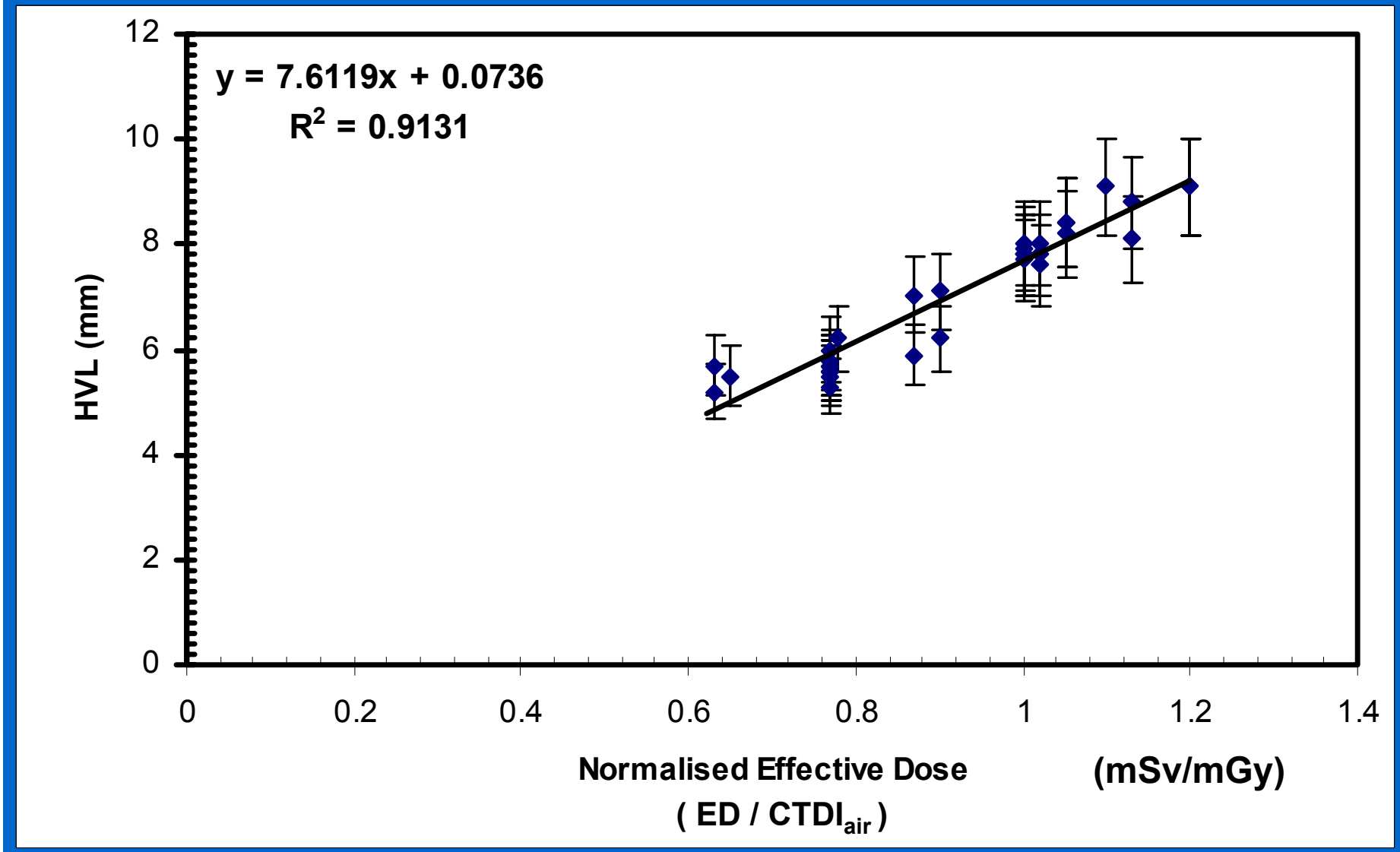
- Multi-variate analysis
  - for combination which gave best correlation
    - ➔ ‘ImPACT’ Factor

ImF = a. (CTDIc / CTDIair)+ b. (CTDIp / CTDIair)+ constant

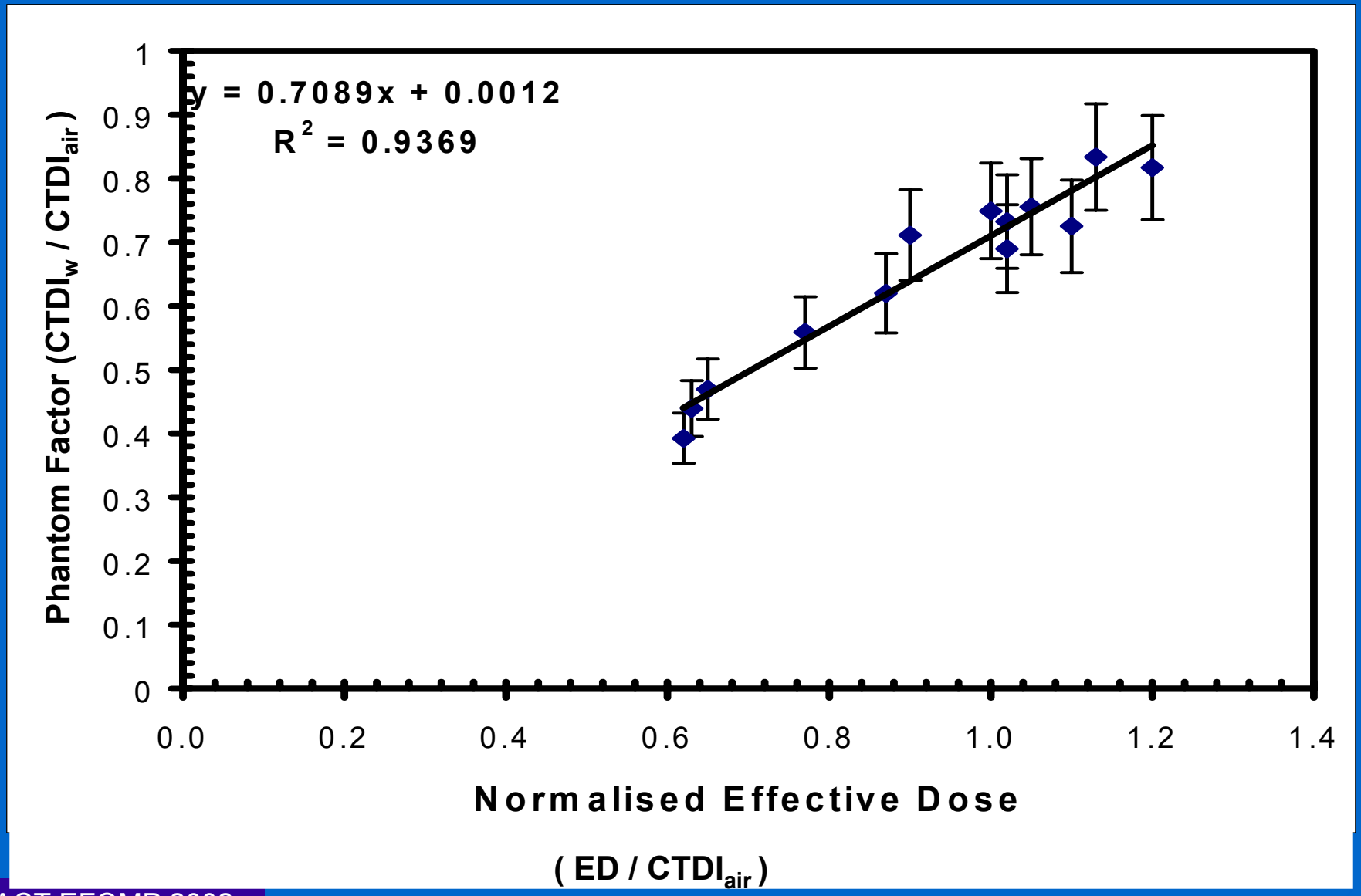
# HVL vs normalised ED



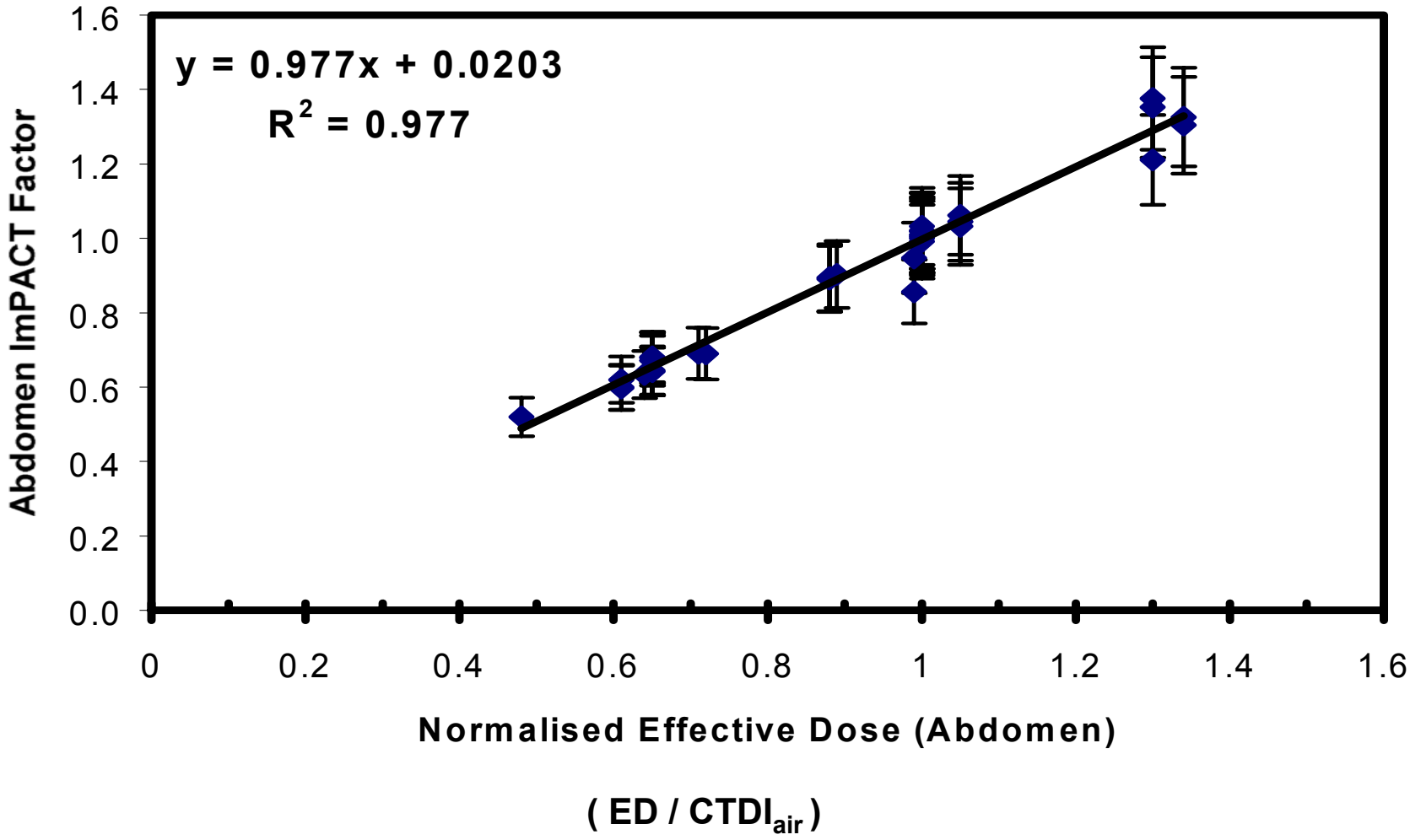
# HVL vs normalised ED



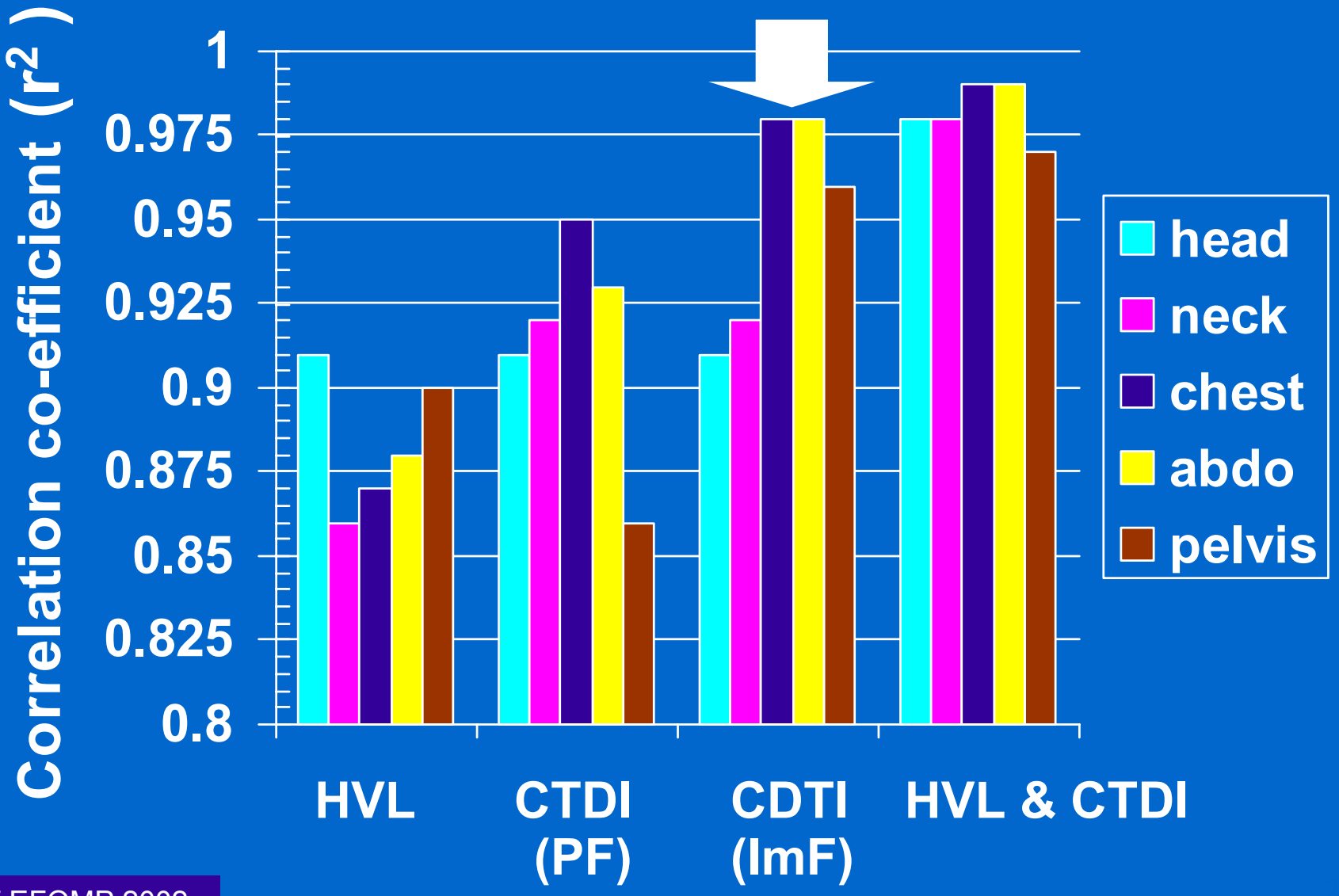
# Phantom factor vs normalised ED



# ImF vs Effective Dose

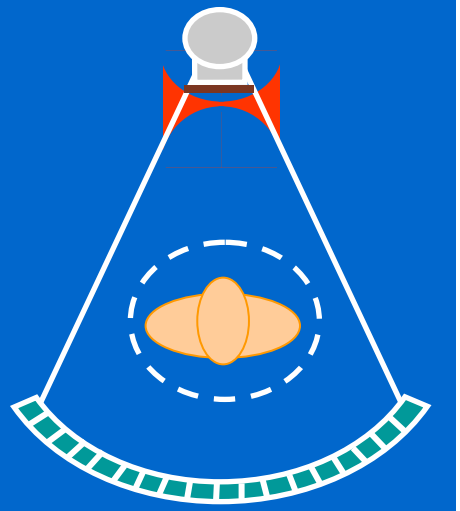


# Correlations for data combinations



# Newer scanner models

- ImF calculated
- Compare to ImFs for SR250 scanners
- Find closest match
- Use that MC dataset



| New Scanner | ImF | SR250 Scanner | ImF | Data Set |
|---|---|---|---|---|
| Philips AV | 0.62 → | xxx | 0.60 | MC 1 |
| | | yyy | 0.75 | MC 2 |

# CTDI data

| | C | D | E | F | G | H | I | J |
|---|---|---|---|---|---|---|---|---|
| 1 | Sub- | Scanner | CTDI (Head) | | | CTDI (Body) | | |
| 2 | group | | Air | Centre | Perip | Air | Centre | Perip |
| 3 | CG.a.130 | CGR CE 10000,12000 | | | | | | |
| 4 | EL.a.120 | Elscint Exel 2400 Elect | 18.8 | 13.2 | 14.5 | 18.5 | 3.5 | 6.2 |
| 5 | EL.a.140 | Elscint Exel 2400 Elect | | | | 25.8 | 5.2 | 8.6 |
| 6 | EL.b.120 | Elscint CT Twin, Helicat | 18.6 | 12.9 | 13.9 | 19.0 | 3.8 | 6.5 |
| 7 | GE.a.120 | GE 8800 / 9000 Series | 14.1 | 6.5 | 6.1 | 14.6 | 2.1 | 4.2 |
| 8 | GE.b.120 | GE 9800 Series | 26.0 | 14.1 | 14.9 | 26.0 | 3.9 | 7.4 |
| 9 | GE.b.140 | GE 9800 Series | 34.1 | 19.4 | 20.0 | 34.1 | 5.7 | 10.0 |
| 10 | GE.c.080 | GE HiLight, HiSpeed, CT/i (No SmB) | 8.5 | 4.2 | 4.5 | 8.5 | 1.0 | 1.9 |
| 11 | GE.c.100 | GE HiLight, HiSpeed, CT/i (No SmB) | 14.0 | 8.2 | 8.3 | 14.0 | 2.2 | 4.3 |
| 12 | GE.c.120 | GE HiLight, HiSpeed, CT/i (No SmB) | 19.3 | 11.4 | 11.9 | 18.8 | 3.2 | 6.1 |
| 13 | GE.c.140 | GE HiLight, HiSpeed, CT/i (No SmB) | 27.0 | 16.8 | 17.2 | 25.8 | 4.8 | 9.0 |
| 14 | GE.d.080 | GE HiSpeed CT/i with SmartBeam | 8.5 | 4.2 | 4.5 | 8.5 | 1.0 | 2.7 |
| 15 | GE.d.100 | GE HiSpeed CT/i with SmartBeam | 14.0 | 8.2 | 8.3 | 13.9 | 2.5 | 5.6 |
| 16 | GE.d.120 | GE HiSpeed CT/i with SmartBeam | 19.3 | 11.4 | 11.9 | 20.4 | 3.8 | 7.3 |
| 17 | GE.d.140 | GE HiSpeed CT/i with SmartBeam | 27.0 | 16.8 | 17.2 | 27.7 | 5.8 | 10.7 |
| 18 | GE.e.120 | GE Max | 38.4 | 18.8 | 17.7 | 38.4 | 5.0 | 8.8 |
| 19 | GE.f.080 | GE Pace, Sytec | 20.1 | 8.0 | 10.0 | 19.2 | 1.9 | 5.3 |
| 20 | GE.f.120 | GE Pace, Sytec | 41.6 | 22.1 | 23.8 | 41.0 | 6.3 | 13.2 |
| 21 | GE.f.140 | GE Pace, Sytec | 55.5 | 30.7 | 33.5 | 54.1 | 9.5 | 18.5 |
| 22 | GE.g.120 | GE Prospeed | 36.6 | 20.8 | 22.2 | 35.0 | 5.4 | 11.0 |
| 23 | GE.g.140 | GE Prospeed | 43.6 | 22.2 | 25.8 | | | |
| 24 | GE.h.080 | GE FX/i, LX/i | 16.3 | 6.7 | 8.2 | 16.3 | 1.5 | 4.3 |
| 25 | GE.h.120 | GE FX/i, LX/I | 33.4 | 18.0 | 19.4 | 33.4 | 5.1 | 10.2 |

ScanCalculation / Phantom / **Scanners** / MatchData / Doses / MonteCarloData / Selections / Version

# ImPACT Factor - scanner matching

| | C | D | K | L |
|---|---|---|---|---|
| 1 | Sub- | Scanner | ImPACT Factor | |
| 2 | group | | Head | Body |
| 3 | CG.a.130 | CGR CE 10000,12000 | 1.08 | 1.06 |
| 4 | EL.a.120 | Elscint Exel 2400 Elect | 1.03 | 0.80 |
| 5 | EL.a.140 | Elscint Exel 2400 Elect | | 0.85 |
| 6 | EL.b.120 | Elscint CT Twin, Helicat | 1.01 | 0.85 |
| 7 | GE.a.120 | GE 8800 / 9000 Series | 0.64 | 0.61 |
| 8 | GE.b.120 | GE 9800 Series | 0.79 | 0.63 |
| 9 | GE.b.140 | GE 9800 Series | 0.82 | 0.69 |
| 10 | GE.c.080 | GE HiLight, HiSpeed, CT/i (No SmB) | 0.73 | 0.47 |
| 11 | GE.c.100 | GE HiLight, HiSpeed, CT/i (No SmB) | 0.83 | 0.67 |
| 12 | GE.c.120 | GE HiLight, HiSpeed, CT/i (No SmB) | 0.85 | 0.73 |
| 13 | GE.c.140 | GE HiLight, HiSpeed, CT/i (No SmB) | 0.88 | 0.80 |
| 14 | GE.d.080 | GE HiSpeed CT/i with SmartBeam | 0.73 | 0.55 |
| 15 | GE.d.100 | GE HiSpeed CT/i with SmartBeam | 0.83 | 0.81 |
| 16 | GE.d.120 | GE HiSpeed CT/i with SmartBeam | 0.85 | 0.81 |
| 17 | GE.d.140 | GE HiSpeed CT/i with SmartBeam | 0.88 | 0.90 |
| 18 | GE.e.120 | GE Max | 0.68 | 0.52 |
| 19 | GE.f.080 | GE Pace, Sytec | 0.66 | 0.44 |
| 20 | GE.f.120 | GE Pace, Sytec | 0.79 | 0.66 |
| 21 | GE.f.140 | GE Pace, Sytec | 0.82 | 0.76 |
| 22 | GE.g.120 | GE Prospeed | 0.83 | 0.66 |
| 23 | GE.g.140 | GE Prospeed | 0.79 | |
| 24 | GE.h.080 | GE FX/i, LX/i | 0.67 | 0.40 |
| 25 | GE.h.120 | GE FX/i, LX/I | 0.80 | 0.65 |

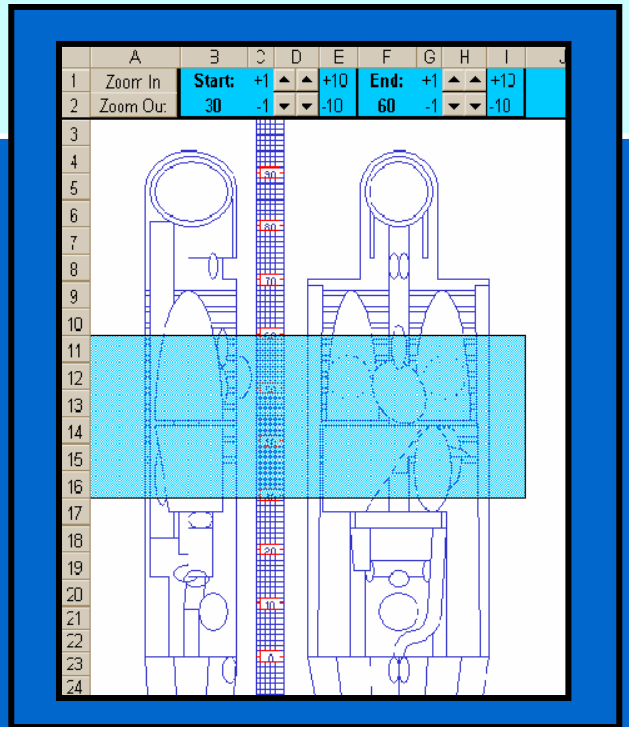
ScanCalculation / Phantom \ **Scanners** / MatchData / Dose

# ImPACT CT Patient Dosimetry Calculator

**version 0.99k, 24/01/2002**

| Scanner Model: | | |
|---|---|---|
| Manufacturer: | Philips | |
| Scanner: | Philips CT Secura | |
| kV: | 120 | |
| Scan Region: | Body | |
| Data Set | MCSET21 | Update Data Set |
| Current Data | MCSET21 | |
| Patient: | | |
| Patient Sex: | | |

| Scan Parameters: | | |
|---|---|---|
| mA | 100 | mA |
| Rotation time | 1 | s |
| mAs / Rotation | 100 | mAs |
| Slice Width | 10 | mm |
| Pitch | 1 | |
| Start Position | 30 | cm Get From Phantom Diagram |
| End Position | 60 | cm |
| CTDI (air) Look up | 19.5 | mGy/100mAs |
| CTDI (soft tissue) | 20.9 | mGy/100mAs |
| ${}_{n}CTDI_{w}$ | 7.6 | mGy/100mAs |




# Organ and Effective Dose

| | Thymus | Thyroid | Urinary Bladder | Uterus | Head Region | Trunk Region | Leg Region | Skeleton | Red Marrow |
|---|---|---|---|---|---|---|---|---|---|
| $\Sigma_v D_f$ | 0.514 | 0.018 | 0.002 | 0.009 | 0.006 | 0.245 | 0.000 | 0.247 | 0.141 |
| $H_T$ | 10.722 | 0.376 | 0.050 | 0.184 | 0.124 | 5.120 | 0.001 | 5.165 | 2.953 |

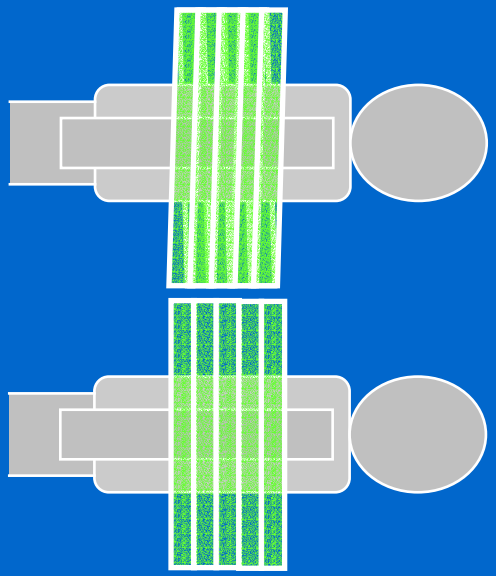
| Organ | $w_T$ | $H_T$ | $w_T.H_T$ |
|---|---|---|---|
| Gonads | 0.2 | 0.101 | 0.020 |
| Bone Marrow (red) | 0.12 | 2.953 | 0.354 |
| Colon | 0.12 | 0.199 | 0.024 |
| Lung | 0.12 | 9.650 | 1.158 |
| Stomach | 0.12 | 8.788 | 1.055 |
| Bladder | 0.05 | 0.050 | 0.003 |
| Breast | 0.05 | 8.510 | 0.426 |
| Liver | 0.05 | 9.044 | 0.452 |
| Oesophagus (Thymus) | 0.05 | 10.722 | 0.536 |
| Thyroid | 0.05 | 0.376 | 0.019 |
| Skin | 0.01 | 2.115 | 0.021 |
| Bone Surface | 0.01 | 5.165 | 0.052 |
| Thymus | 0.025 | 10.722 | 0.268 |
| Remainder 2 | 0.025 | 2.293 | 0.057 |
| **Total Effective Dose (mSv)** | | | **4.444** |

| Remainder Organs | $H_T$ |
|---|---|
| Adrenals | 10.010 |
| Brain | 0.017 |
| Upper Large Intestine | 1.141 |
| Small Intestine | 0.843 |
| Kidney | 8.455 |
| Pancreas | 8.856 |
| Spleen | 9.182 |
| Thymus | 10.722 |
| Uterus | 0.184 |
| Muscle | 2.315 |

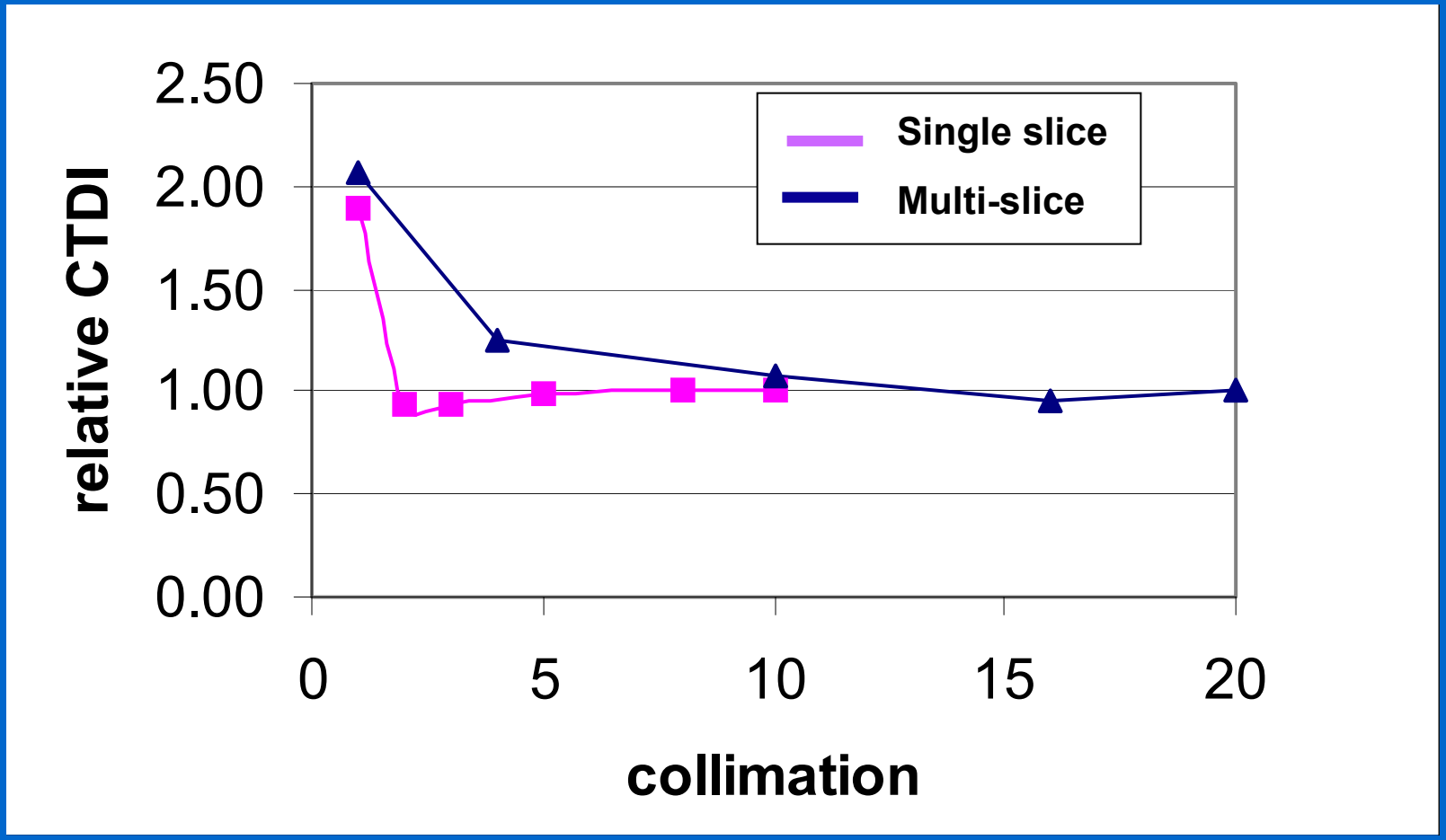
| | |
|---|---|
| Pitch adjusted $CDTI_w$ (mGy) | 7.6 |
| DLP (mGy.cm) | 227.7 |

# Spiral scanning

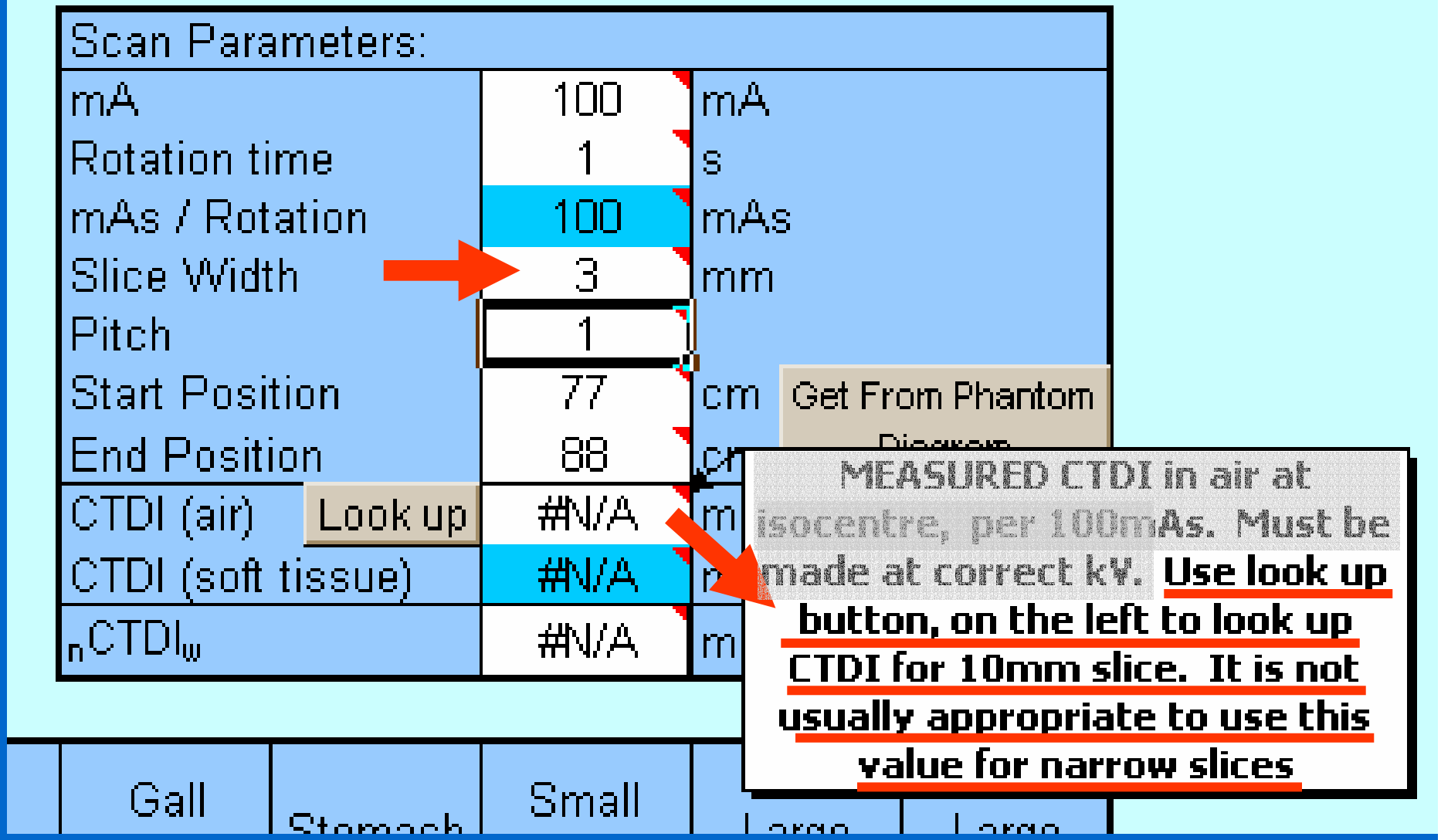
| Scan Parameters: | | | |
|---|---|---|---|
| kV | 120 | kV | |
| mA | 100 | mA | |
| Rotation time | 1 | s | |
| mAs / Slice | 100 | mAs | |
| Slice Width | 10 | mm | |
| Pitch | 1 | | |
| Start Position | 30 | cm | Get From Phantom Diagram |
| End Position | 59.5 | cm | |
| CTDI (air) Look up | 19.5 | mGy/100mAs | |
| CTDI (soft tissue) | 20.9 | mGy/100mAs | |



# CTDI and collimation



# CTDI and slice width



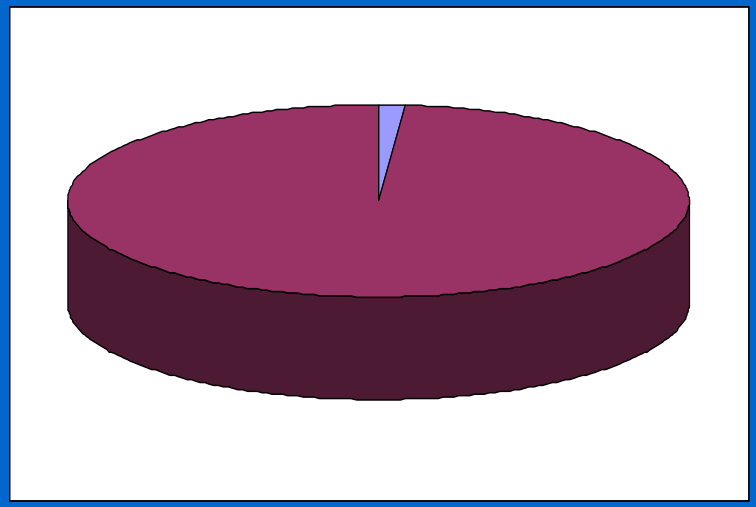
# Multi-slice scanners

| Scan Parameters: | | |
|---|---|---|
| mA | 100 | mA |
| Rotation time | 1 | s |
| mAs / Rotation | 100 | mA |
| Slice Width | 10 | m |
| Pitch | 1 | |
| Start Position | 77 | cm |
| End Position | 88 | cm |
| CTDI (air) Look up | 17.4 | mGy/100mAs |
| CTDI (soft tissue) | 18.6 | mGy/100mAs |
| ${}_nCTDI_w$ | 12.9 | mGy/100mAs |

**Collimated slice width. For multi-slice scanners use total beam width, not detector width**

# ImPACT 1996-1997 survey

- Enabled NRPB datasets to be used for 99% of installed scanners in the UK



- New scanners are measured routinely by ImPACT and published

CTDI in air and in phantom → ImF

# EUR16262 Quality Criteria for CT

- Dose Reference Levels $CTDI_w$, DLP

| Sub-group | Scanner | CTDI (Head) | | | CTDI (Body) | | |
|---|---|---|---|---|---|---|---|
| | | Air | Centre | Perip | Air | Centre | Perip |
| CG.a.130 | CGR CE 10000,12000 | | | | | | |
| EL.a.120 | Elscint Exel 2400 Elect | 18.8 | 13.2 | 14.5 | 18.5 | 3.5 | 6.2 |
| EL.a.140 | Elscint Exel 2400 Elect | | | | 25.8 | 5.2 | 8.6 |
| EL.b.120 | Elscint CT Twin, Helicat | 18.6 | 12.9 | 13.9 | 19.0 | 3.8 | 6.5 |
| GE.a.120 | GE 8800 / 9000 Series | 14.1 | 6.5 | 6.1 | 14.6 | 2.1 | 4.2 |
| GE.b.120 | GE 9800 Series | 26.0 | 14.1 | 14.9 | 26.0 | 3.9 | 7.4 |
| GE.b.140 | GE 9800 Series | 34.1 | 19.4 | 20.0 | 34.1 | 5.7 | 10.0 |
| GE.c.080 | GE HiLight, HiSpeed, CT/i (No SmB) | 8.5 | 4.2 | 4.5 | 8.5 | 1.0 | 1.9 |
| GE.c.100 | GE HiLight, HiSpeed, CT/i (No SmB) | 14.0 | 8.2 | 8.3 | 14.0 | 2.2 | 4.3 |
| GE.c.120 | GE HiLight, HiSpeed, CT/i (No SmB) | 19.3 | 11.4 | 11.9 | 18.8 | 3.2 | 6.1 |
| GE.c.140 | GE HiLight, HiSpeed, CT/i (No SmB) | 27.0 | 16.8 | 17.2 | 25.8 | 4.8 | 9.0 |
| GE.d.080 | GE HiSpeed CT/i with SmartBeam | 8.5 | 4.2 | 4.5 | 8.5 | 1.0 | 2.7 |

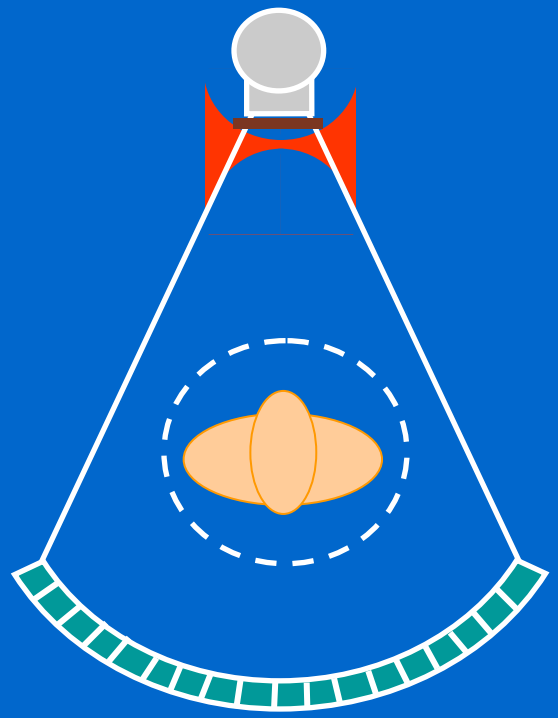
$$CTDI_w = 1/3 CTDI_c + 2/3 CTDI_p$$

c = centre positon, p= periphery position

| | |
|---|---|
| Pitch adjusted $CDTI_w$ (mGy) | 7.6 |
| DLP (mGy.cm) | 227.7 |

# Scanner models

- Name can be misleading
  - Siemens Plus, Plus 4
  - Philips LX, AV Expander
- Filtration can change on existing scanner models
  - name stays the same
  - need to identify by model name & date

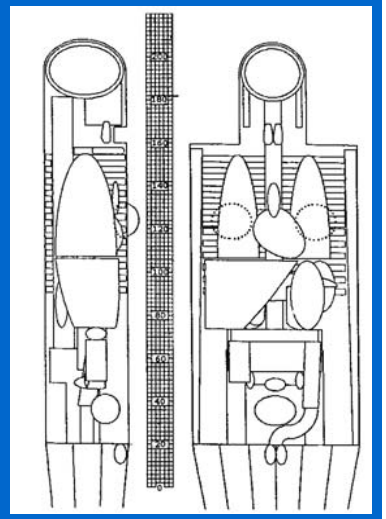


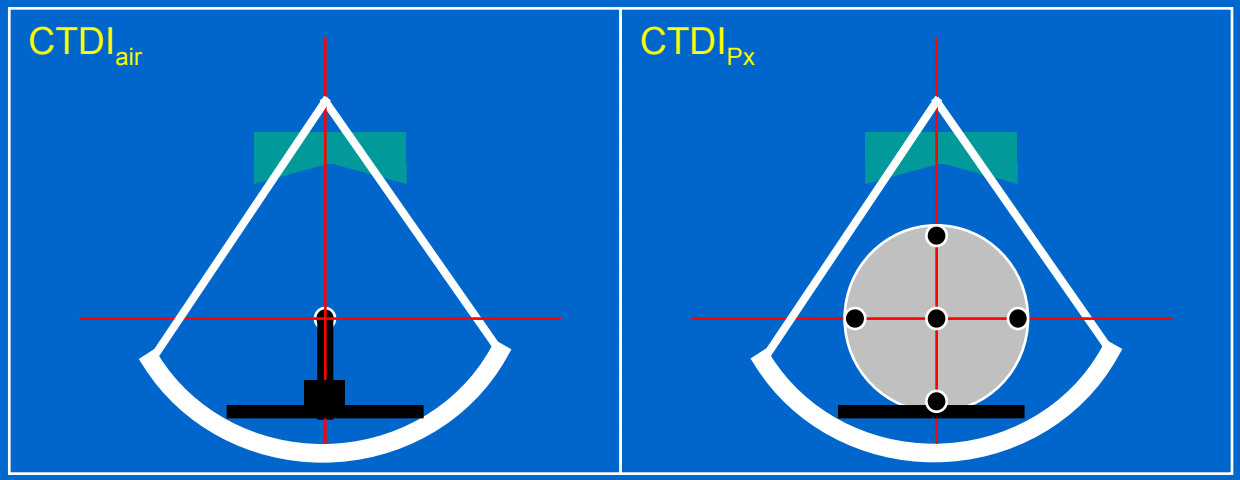
# ImPACT data

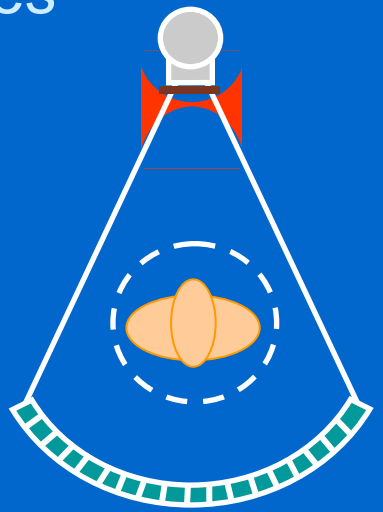
- Survey data tried to minimise errors
  - chambers cross checked
  - extensive work checking consistency of data
    - data > 10% from mean of a group looked at
- newer scanners use our own data
    - checked against manufacturers data
- Data for 10 mm slices only
    - used for matching
    - look-up tables simplified
    - need focal spot with narrow slices

# ImPACT survey

- Goal achieved
  - matching new scanners to NRPB MC datasets
- Additional use for phantom CTDI
  - EUR16262 (10 mm data)
- Data continuously updated
  - Need to keep aware of manufacturers' changes





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- Participating centres


ImPACT

Imaging Performance Assessment of CT Scanners

*A Medical Devices Agency Evaluation Group*

MDA MEDICAL DEVICES AGENCY

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