Uncertainty Assessment in Computational Dosimetry:

A comparison of Approaches

Euratom VI Framework Programme

Medical Staff Dosimetry

Summary of the Submitted Problem Solutions

Medical Staff Dosimetry

Restricted Problem – CONRAD WP4 & WP7

Jean-Marc Bordy -	**Design of a Realistic Calibration Field for Diagnostic Radiology**
Frank Schultz -	**Simulation of an Interventional Cardiac Catheterization Procedure**
Lara Struelens -	**Summary of the Submitted Problem Solutions**

Outline

Problem 1:

A comparison of calculated results and experimental data concerning the characterization of the scattered field

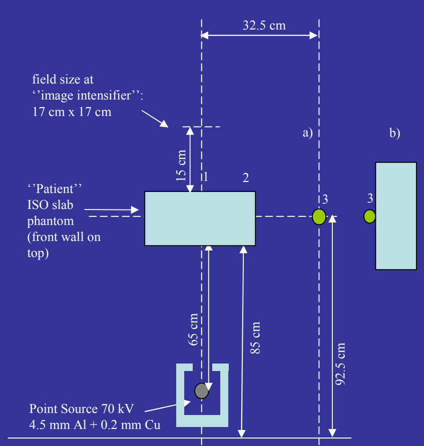
- Belgium (MCNPX) - The Netherlands (MCNP4C) - Slovakia (MCNP4C)
- Portugal (MCNPX) - Denmark (Penelope 2006)

Problem 2:

A comparison of calculated results concerning the dose to the interventional cardiologist

- Belgium (MCNPX) - The Netherlands (MCNP4C)
- Portugal (MCNPX) - Denmark (Penelope 2006)

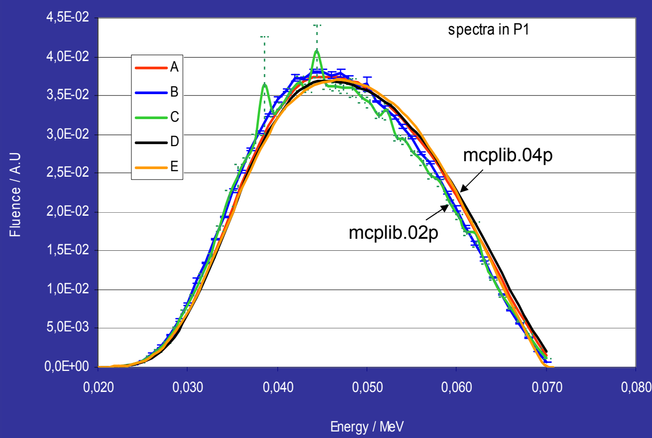
Problem 1: A comparison of calculated results and experimental data concerning the characterization of the scattered field



- Calculate energy spectra at P1 and P2
- Calculate 'dosemeter' readings (P3) per unit of dose-area-product (DAP)
  a. Free-in-air
  b. In front of 'cardiologist' phantom
- Comparison with experiments: intercomparison of APDs at CEA and IRSN (CONRAD-WP7)

Lara Struelens - Medical staff dosimetry: Summary of the Submitted Problem Solutions

Results: **Energy spectra at P1**



Average energy:

- A: 47.97 keV ± 0.06%
- B: 47.26 keV ± 0.25%
- C: 47.26 keV ± 1.08%
- D: 48.23 keV ± 0.04%
- E: 47.96 keV ± 0.18%

Standard deviation: 0.90%

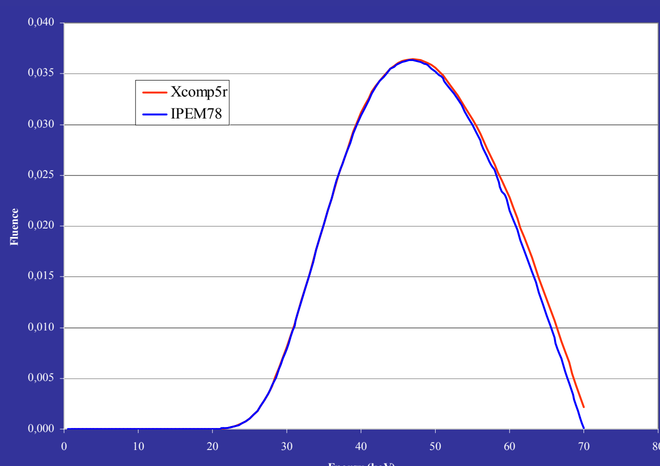
- Cross section libraries
- Source spectrum: Xcomp5r ↔ IPEM78

CONRAD WP4 BOLOGNA 8-10 October 2007

Lara Struelens - Medical staff dosimetry:
Summary of the Submitted Problem Solutions

SCK • CEN
STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ÉTUDE DE L'ÉNERGIE NUCLÉAIRE

source spectrum generator



- A: Xcomp5r
- B: IPEM78
- C: Xcomp5r
- D: Xcomp5r
- E: Xcomp5r

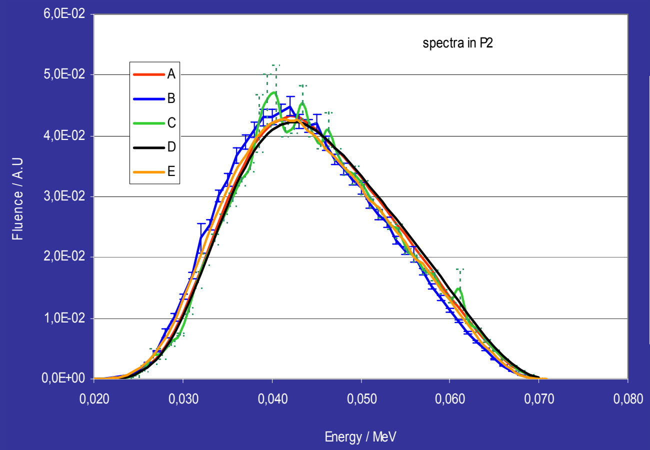
Source spectrum: Xcomp5r ↔ IPEM78

CONRAD WP4 BOLOGNA 8-10 October 2007

Lara Struelens - Medical staff dosimetry:
Summary of the Submitted Problem Solutions

SCK • CEN
STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ÉTUDE DE L'ÉNERGIE NUCLÉAIRE

Results: Energy spectra at P2

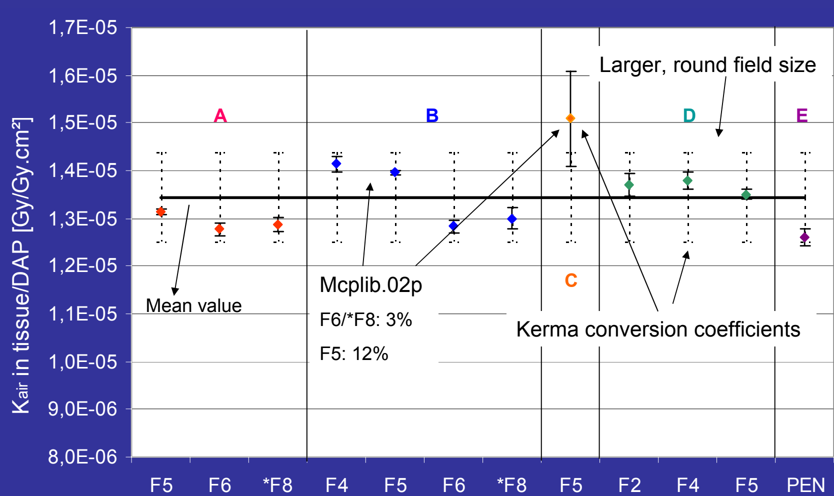


Average energy:
- A: 45.10 keV ± 0.07%
- B: 44.10 keV ± 0.55%
- C: 45.15 keV ± 1.50%
- D: 45.40 keV ± 0.07%
- E: 44.53 keV ± 0.51%

Standard deviation: 1.18%

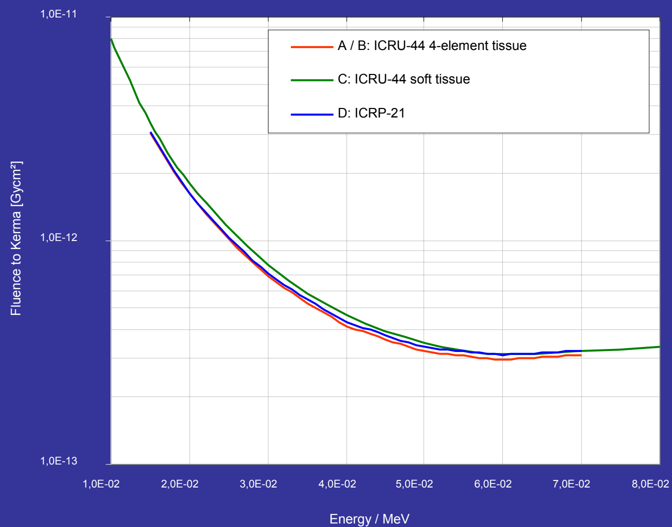
- Cross section libraries
- Source spectrum: Xcomp5r ↔ IPEM78

Results: 'Dosemeter readings' free-in-air

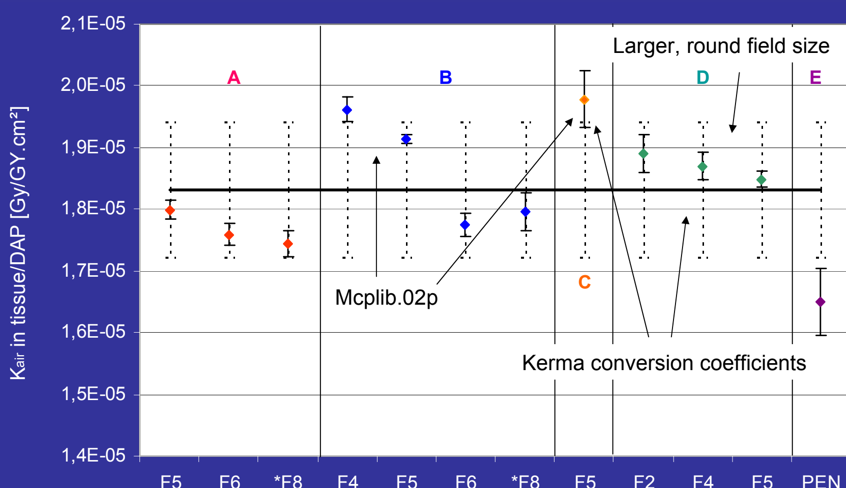


conversion coefficients

$$K = \int \overline{\Phi}_E \cdot E \cdot \left(\frac{\mu_{tr}}{\rho}\right) \cdot dE$$

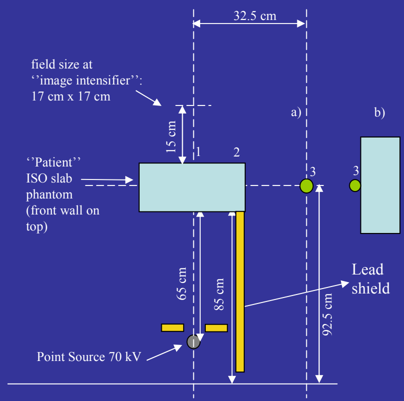


Results: 'Dosemeter readings' in front of slab phantom



Lara Struelens - Medical staff dosimetry:
Summary of the Submitted Problem Solutions

Comparison with experiments



APD intercomparison with same ISO slab geometry.

CEA: pulsed radiation

square field

IRSN: continuous radiation

round field

Comparison with experiments

Measurements:

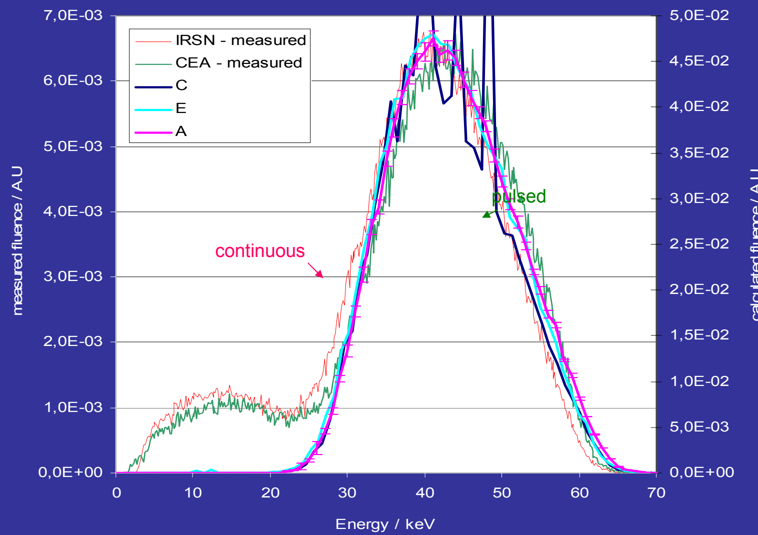
- **Energy spectra in point 3 free-in-air (CdTe XR-100T spectrometer)**

  → compared to calculated spectra in point 3 (A, C and E)

- Air kerma K_{air} at point 3 free-in-air (ionisation chamber)

  → compared to calculated values in point 3 (A, B, C, D and E)

Comparison with experiments



Comparison with experiments

Measurements:

- Energy spectra in point 3 free-in-air (CdTe XR-100T spectrometer)

  → compared to calculated spectra in point 3 (A, C and E)

- **Air kerma K_{air} at point 3 free-in-air (ionisation chamber)**

  → compared to calculated values in point 3 (A, B, C, D and E)

Comparison with experiments

- Air kerma K_{air} at point 3 free-in-air
- Measurements with ionisation chamber
  - Pulsed: 15.7 μGy/Gycm² (k = 2 ; uncertainty: 6.2%)
  - Continuous: 10.2 μGy/Gy.cm² (k = 2 ; uncertainty: 7.3%)
- Calculations Only results using mcplib.04p
  - Kerma in tissue → K_{air} : $(\mu_{en}/\rho)_{air}$ / $(\mu_{en}/\rho)_{tissue}$

    (ICRU-44 ; the complete spectra from institutes was taken into account)
  - Average K_{air} = 12.3 μGy/Gy.cm² (uncertainty: 1.5 %)
- Systematic error: 22% (pulsed) and -20% (continuous)

Conclusions problem 1

- Problems were solved using different codes: MCNP4C, MCNPX and Penelope
- The main differences between the calculated results were the choice of library and the choice of dose conversion coefficients

  → flux tallies are sensitive to angular distributions of secondary particles
  ⇒ recommended to use the latest set of data tables: mcplib.04p

  → differences were larger than the statistical uncertainties
- Systematic error of ± 20% between experimental and calculated data

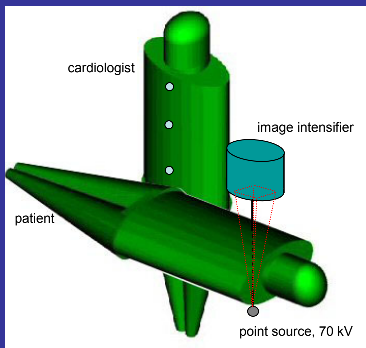
  → Where do the differences in experimental data come from?

  → calculations done in a sphere filled with tissue ↔ air kerma measurement

  → Simulation of environment necessary?

Problem 2: A comparison of calculated results concerning the dose to the interventional cardiologist

A representative clinical practice



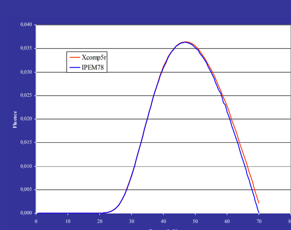
- Calculate ‘dosemeter readings’ per DAP at waist, chest and neck level
  a. Without protective clothing
  b. Above and under lead-apron
- Calculate effective dose to the cardiologist per DAP
  a. Without protective clothing
  b. With protective clothing

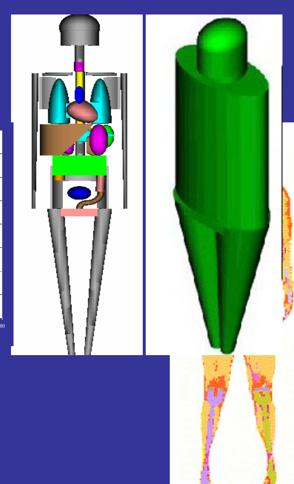
Geometry, technical parameters: pres. F. Schultz

Problem 2: A comparison of calculated results concerning the dose to the interventional cardiologist

Implementation of clinical situation by participant:

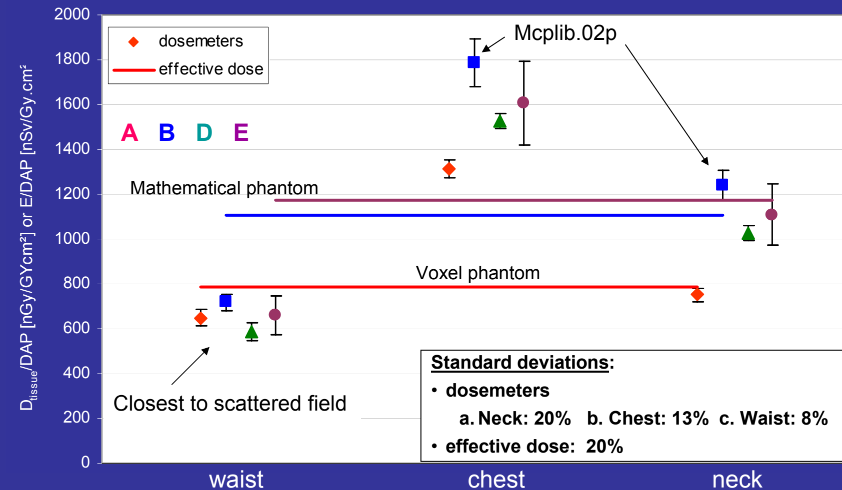
- choice of spectrum generator
  - A, D and E: X-comp5r
  - B: IPEM78



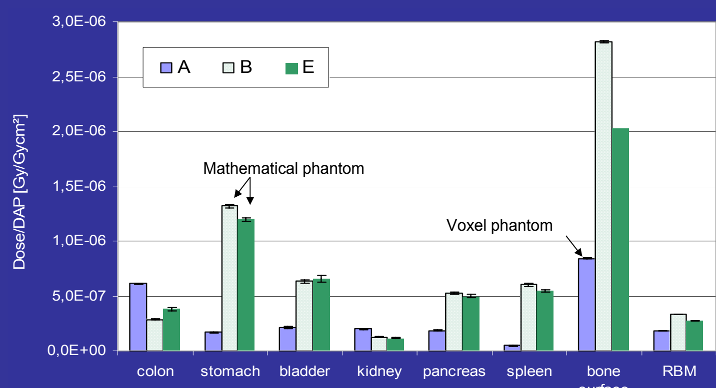


- choice of phantoms
  - Patient: mathematical phantom (ADAM, Bodybuilder)
  - Staff: B, D and E: ADAM mathematical phantom
    A: MAX voxel phantom

Results: **without protective clothing** (4 participants)



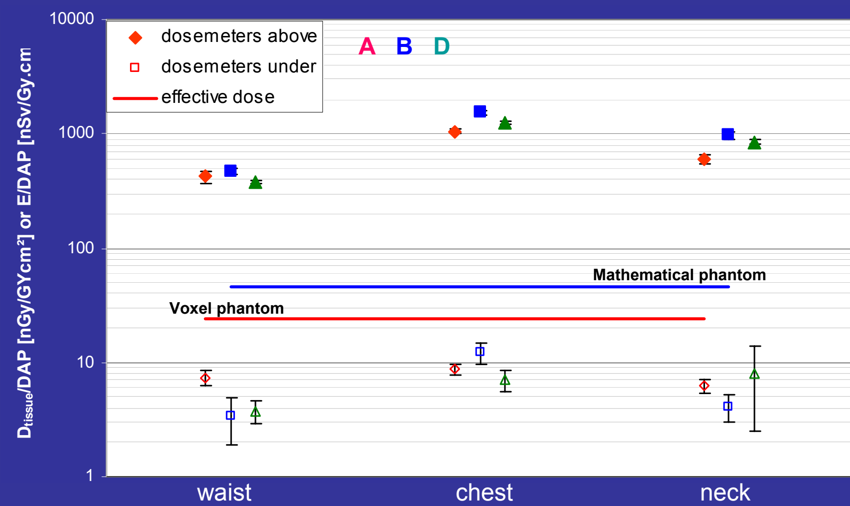
Results: **without protective clothing: organ doses**



- Different phantoms
- Calculation method for skeleton and Red Bone Marrow (RBM): skeleton mixture, distribution of RBM, correction factors, …

Lara Struelens - Medical staff dosimetry:
Summary of the Submitted Problem Solutions
SCK•CEN
STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ÉTUDE DE L'ÉNERGIE NUCLÉAIRE

Results: with protective clothing (3 participants)



Results: with protective clothing

differences:

- dosemeters above
  - a. Neck: 24% b. Chest: 19% c. Waist: 11%
- dosemeters under
  - a. Neck: 32% b. Chest: 28% c. Waist: 45%
- effective dose: 47% (only 2 results)

Ratio $H_p(10)$ / E:

- dosemeters **above** apron: **average overestimation of E by a factor of 25**
  minimum: factor 10 (waist dosemeter)
  maximum: factor 43 (chest dosemeter)
- dosemeters **under** apron: **average underestimation of E by a factor 0.22**
  minimum: factor 0.35 (chest dosemeter)
  maximum: factor 0.07 (waist dosemeter)

⇒ Need of algorithm to combine 2 dosemeters for conservative estimation of E

Results: with protective clothing

Example of 2 existing algorithms

1. From a large Belgian study: $E_{est} = 2.25 \times H_p(10)_{thorax, under} + 0.097 \times H_p(10)_{neck, above}$

   Results for A: E_{est} = 77 nSv/Gy.cm² and E_{calc} = 24 nSv/Gy.cm²
   ratio E_{est} / E_{calc} = 3.16 (overestimation of 216%)

   Results for B: E_{est} = 122 nSv/Gy.cm² and E_{calc} = 45 nSv/Gy.cm²
   ratio E_{est} / E_{calc} = 2.69 (overestimation of 169%)

2. From Wambersie: $E_{est} = 1.0 \times H_p(10)_{waist, under} + 0.1 \times H_p(10)_{neck, above}$

   Results for A: E_{est} = 67 nSv/Gy.cm² and E_{calc} = 24 nSv/Gy.cm²
   ratio E_{est} / E_{calc} = 2.74 (overestimation of 174%)

   Results for B: E_{est} = 101 nSv/Gy.cm² and E_{calc} = 45 nSv/Gy.cm²
   ratio E_{est} / E_{calc} = 2.22 (overestimation of 122%)

NOTE: result for only 1 configuration (PA thorax), 1 spectrum, 1 position of cardiologist!!!

Conclusions problem 2

Monte Carlo modelling for medical staff dosimetry – difficulties

- A realistic clinical situation is a combination of a very large amount of parameters
  - Beam projections (PA, AP, LAT, OBL, …)
  - Field sizes (17 x 17 cm²)
  - Irradiated parts of the patient (head, thorax, abdomen, …)
  - Energy spectra: combination of tube voltage and filtration
    (60, 70 - 100 kVp; 2.0-4.0 mm Al + 0.1,0.2-0.6 mm Cu)
  - Position of the worker in respect to the scattered radiation field
- There is **a large influence** on how a clinical practice is implemented in a calculation problem for the evaluation of the effective dose to the worker
  - Larger difference in effective dose than in dosemeter results between participants
    - ⇒ Different correlation between dosemeters results and effective dose
    - ⇒ Different results between participants when 1 specific algorithm is used

Conclusions problem 2

- Minimise this influence by

  → type of phantom, organ dose calculation

  - 1 reference phantom (voxelised) for dose and radiation protection studies

  → data libraries, statistical uncertainties

  - most recent libraries
  - under lead apron: variance reduction techniques

- There will always remain a large systematic uncertainty between calculation results and reality due to the difference in anatomy between real persons and a reference phantom

Thanks to all participants !!!

CONRAD WP4 BOLOGNA 8-10 October 2007
Lara Struelens - Medical staff dosimetry:
Summary of the Submitted Problem Solutions
SCK • CEN STUDIECENTRUM VOOR KERNENERGIE CENTRE D'ÉTUDE DE L'ÉNERGIE NUCLÉAIRE