EURADOS Intercomparisons in Computational Dosimetry

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EURADOS

A brief history of Working Group 6

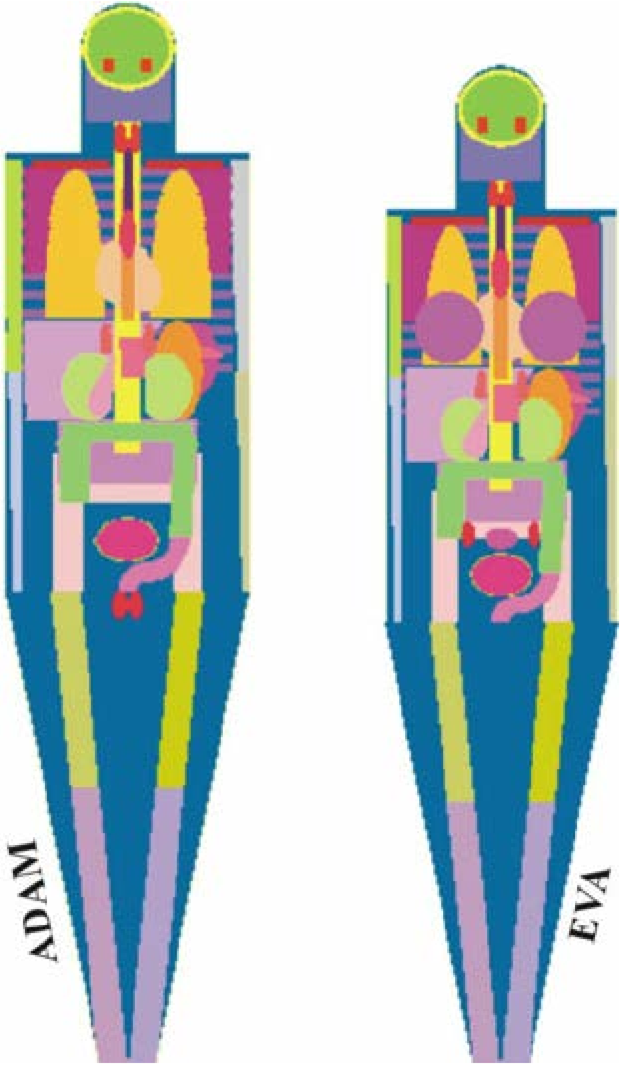
- EURADOS WG 6 is the only WG that has existed since EURADOS was founded in 1982
- The importance of Computational Dosimetry as a topic for research was hence already recognized
- In those 40 years, the WG has only had five chairs: Siegfried Wagner, Bernd Siebert, Gianfranco Gualdrini, Rick Tanner & Hans Rabus
- WG6 has made major contributions to the EURADOS work programme over four decades
- It continues in a robust state with several new participants at this Annual Meeting
- **There have been too many contributors to fairly credit them all in this presentation**
- I first attended a Computational Dosimetry meeting in 1994 as a novice MCNP-4A user… (though Maria Zankl was already a well established WG4 member)
- At that time the scientists doing Monte Carlo were concentrated in WG6, now every WG has scientists doing Monte Carlo

A brief history of Working Group 6

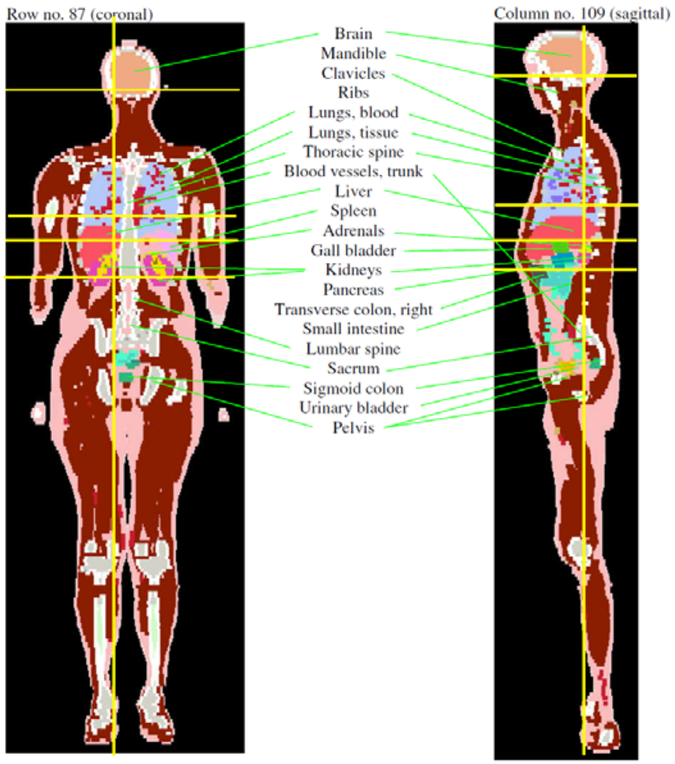
- The area of computational dosimetry has developed hugely over these 40 years
- In the early 1990s, the codes used were often "home-made"
  - These codes had the benefit of being very well understood by their often sole "user"
  - They were limited in their scope because of the time a single person can commit to development
  - They tended to retire with their originator!
  - **They had the crucial benefit of independence**
- The "all singing, all dancing" codes we have today were beginning to be used in Radiation Protection and Dosimetry
  - MCNP did not transport electrons
  - EGS only transported photons and electrons
  - Fluka, GEANT, Penelope… were not yet available to the general radiation protection community

A brief history of Working Group 6 – the 1990s

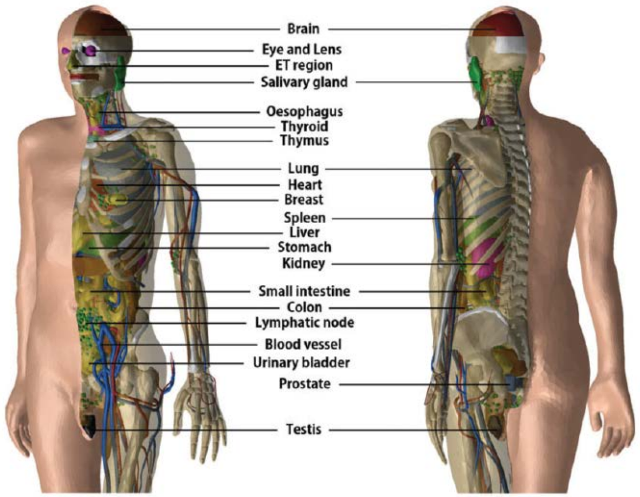
- Efforts were being made to produce coupled calculations
  - The ENEA group under Gianfranco Gualdrini was introducing electron transport to MCNP-BO
  - But it was still experimental…
- Calculations tended to be performed on mainframe computers
  - Needed to compete with other users for cpu!
  - **Getting calculations to converge was difficult**, especially for complex geometries
    - There was a big emphasis on variance reduction
    - Detailed cross-sections might be avoided to prevent issues with memory
  - MIRD phantoms (right) were being replaced by voxel phantoms
  - Major codes, with the benefit of many person-years of development, were becoming widespread



A brief history of Working Group 6 – more recent



- Everyone is now using one of the major codes
- Most people run their code on a PC, laptop or PC cluster
- MIRD phantoms have largely become obsolete
- Voxel phantoms (left) had become the standard but now all the excitement concerns mesh phantoms (right)
- Getting convergence is rarely a problem, except for mesh phantoms…



EURADOS in the last 10 years

- Intercomparisons of personal and area dosemeters have become a core part of the EURADOS work programme (via WGs 2 & 3)
- This is recognized in the current EURADOS strategic research agenda:
  - "Harmonisation, education and training are also key activities for EURADOS, through the organisation of **intercomparisons** (e.g. in individual and environmental monitoring, internal dose assessment and **computational dosimetry** methods)…"
  - It is also a vital part of the accreditation of dosimetry services via EN ISO/IEC 17025:2017 which requires independent assessments of performance:

3.3
interlaboratory comparison
organization, performance and evaluation of measurements or tests on the same or similar items by two or more laboratories in accordance with predetermined conditions

[SOURCE: ISO/IEC 17043:2010, 3.4]

3.4
intralaboratory comparison
organization, performance and evaluation of measurements or tests on the same or similar items within the same *laboratory* (3.6) in accordance with predetermined conditions

3.5
proficiency testing
evaluation of participant performance against pre-established criteria by means of *interlaboratory comparisons* (3.3)

EURADOS Intercomparisons – what are they?

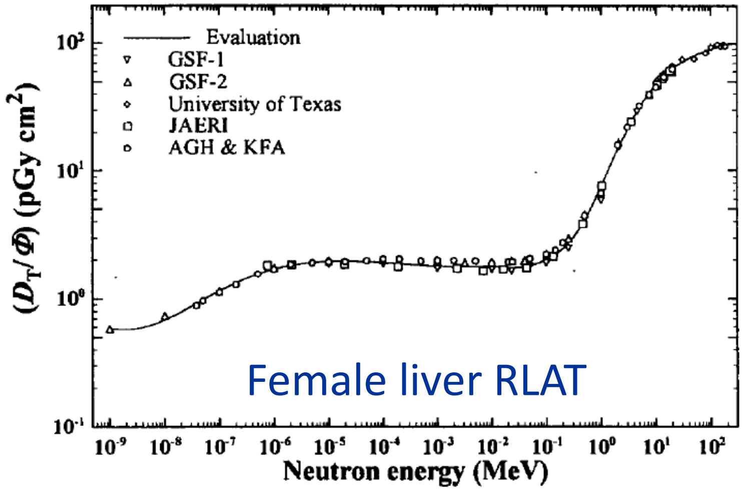
- Considering two types of intercomparison:
  - Type 1: Scientists within the WGs working together to get convergence of their results
  - Type 2: Problems set by the WG and distributed to participants to attempt
- As far as I can tell, the first EURADOS intercomparison was actually an unfolding exercise (Type 1):
  - ALEVRA, A., SIEBERT, B., AROUA, A., BUXEROLLE, M., GRECESCU, M., MATZKE, M., PERKS, C., SCHRAUBE, H., THOMAS, D. & ZABOROWSKI, H. Unfolding Bonner-Sphere data: a European intercomparison of computer codes. Report PTB-1, 22-90-1, 1990.
  - I have been unable to obtain a copy of this report so I have not results or pictures to show you!

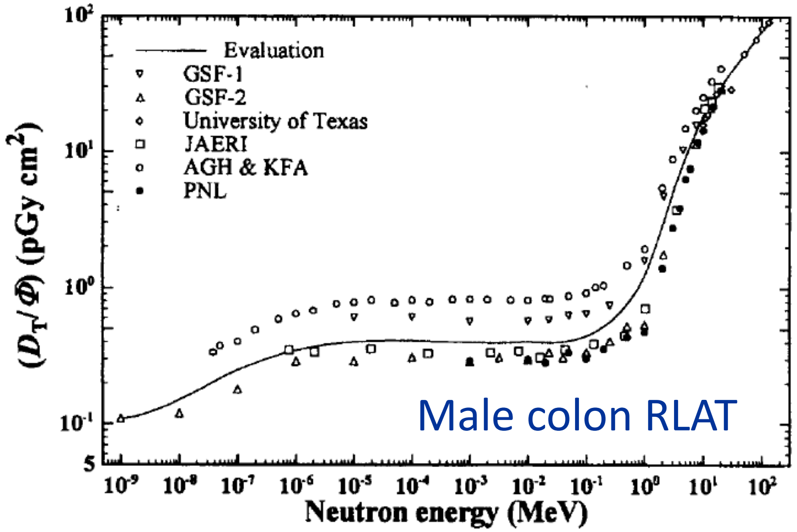
EURADOS intercomparisons – what is the right answer?

- Intercomparisons of Type 1 try to converge on the optimum solution
- Intercomparisons of Type 2 compare submitted results with the "right answer"
  - But what is "right"?
  - We must have something to compare the participants solution with
  - Sometimes we use the "author's" solution, but cannot be sure that it is even the "best" solution
  - There will be variation between solutions not caused by mistakes
    - Simple statistical variation
    - Different input data
    - Different models
    - Different codes
  - **Generally, it is quite clear when a solution deviates significantly from the reference**

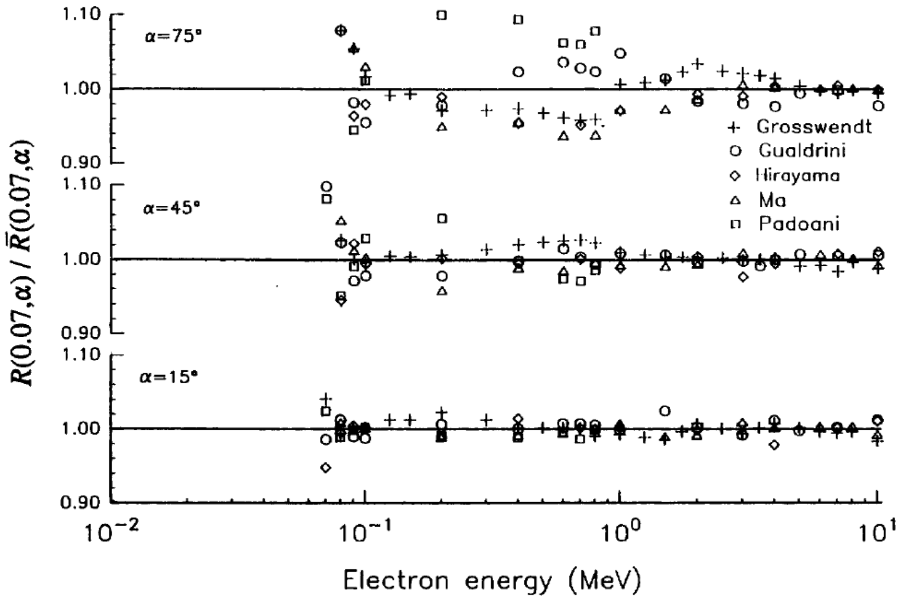
ICRU Report 57/ICRP Publication 74

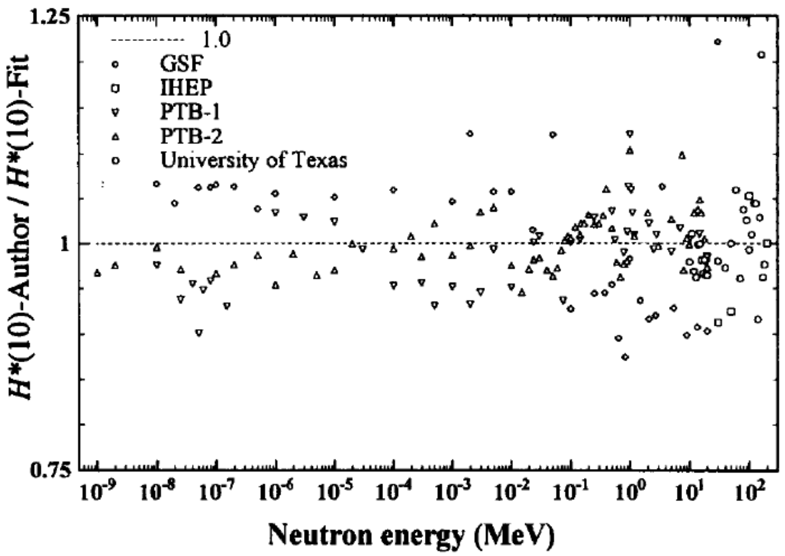
- ICRP 1996. Conversion coefficients for use in radiological protection against external radiation. ICRP Publication 74. Ann. ICRP, 26.
- ICRU 1998. Conversion Coefficients for use in Radiological Protection Against External Radiations. ICRU Report 57. Bethesda, Maryland: ICRU.
- **Reports were produced by EURADOS WG6 and are still in use today.**
- In reality this was a Type 1 exercise, with the WG members contributing solutions, incorporating external solutions and coming up with a best fit.

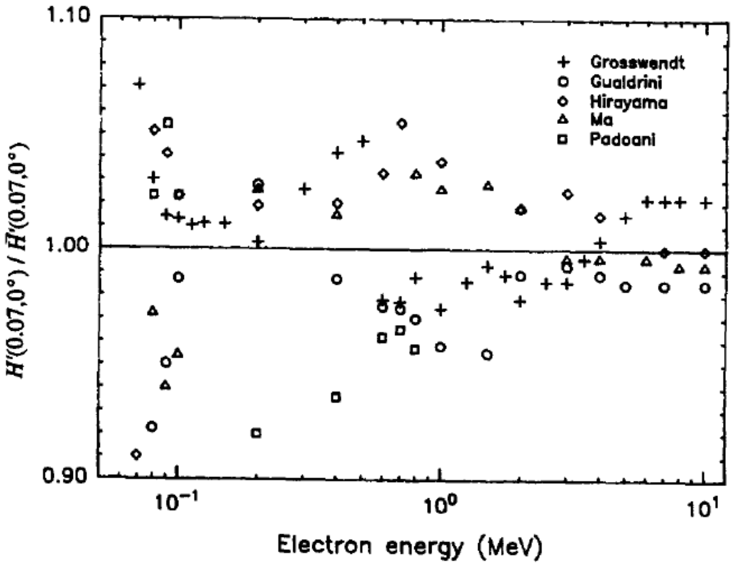




ICRU Report 57/ICRP Publication 74







- Electron & neutron transport were particularly difficult
- Phantoms were not always consistent
- Thermal neutron transport not always invoked
- Kerma approximation used throughout – necessary!

EURADOS QUADOS intercomparison

- **QUA**lity **A**ssurance of computational tools for **DO**Simetry
  - First large scale WG6 intercomparison open for participants anywhere in the world
  - Eight problems with:
    - Relatively easy geometry specification
    - No excessive computation time required
    - Rigorous unambiguous specification of the problems
  - A Concerted Action of the European Commission (FIGD-CT-2000-20062):
    - An intercomparison aimed at evaluating the use of computational codes for dosimetry in radiation protection and medical physics.
    - Open to all users of Monte Carlo, analytic and semi-analytic codes or deterministic methods, from both inside and outside the European Union.

EURADOS QUADOS intercomparison

- Provide a snapshot of the methods and codes currently in use
- Furnish information on the methods used to assess the reliability of computational results
- Disseminate “good practice” throughout the radiation dosimetry community
- Provide users with an opportunity to quality assure their procedures
- Inform the community about the benefits of sensitivity and uncertainty analysis
- Inform the community about more sophisticated approaches that may be available to them

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EURADOS QUADOS intercomparison

- **Not intended as a comparison of codes**
  - We cannot conclude the code is at fault
  - If the code cannot be used for the problem, the user should have known
- Intended as a comparison of usage
- Solutions normalized, where appropriate to the authors' solutions
- It is not intended to imply that the author got the correct result
- Use of an average would be impractical
- None of the problems have good experimental data
- Taking an average of the "good" solutions is not practical

EURADOS QUADOS intercomparison

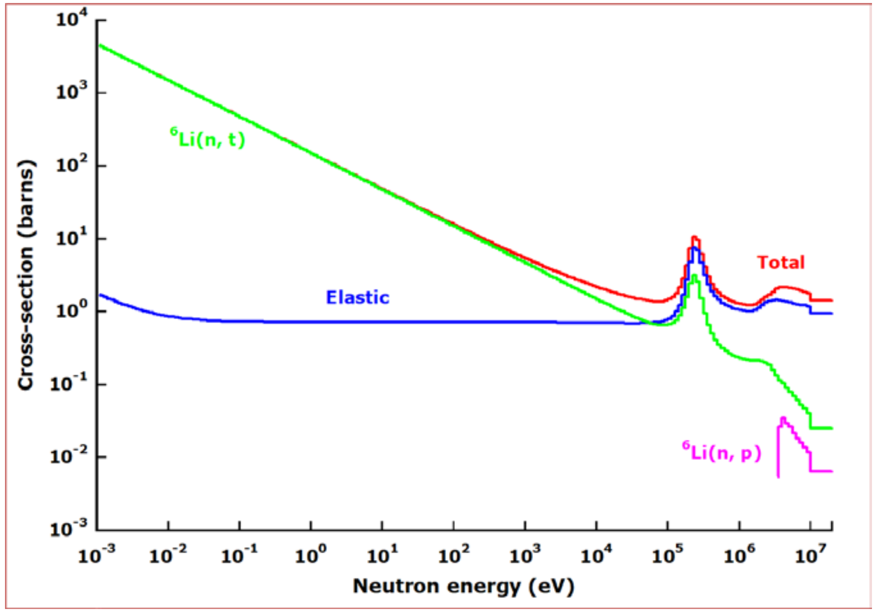
- P1: Brachytherapy - anisotropy/depth-dose of 192Ir g-source
- P2: Endovascular: dose profile of a 32P b- source
- P3: Eye therapy with 50 MeV proton beam
- **P4: TLD-albedo dosemeter response and backscatter**
- P5: Photon phantom backscatter for ISO x-ray beams
- P6: ^{252}Cf-source and shadow cone in a Calibration room
- P7: Ge detector PHD for 15 keV to 1 MeV photons
- P8: Simplified ^{3}He instrument in a consistency jig

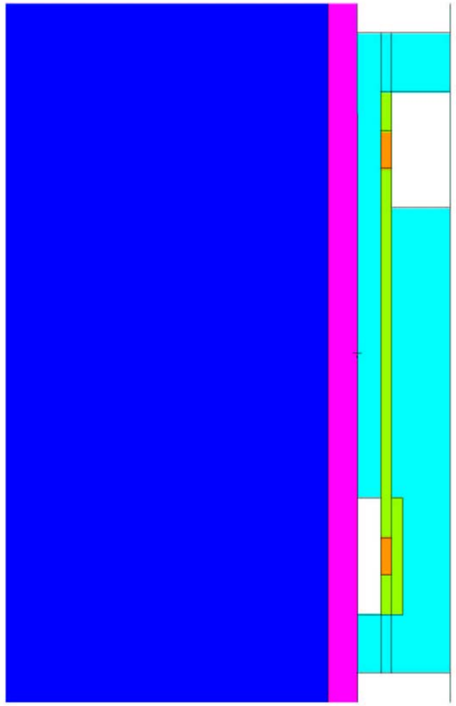
EURADOS QUADOS intercomparison

- Action culminated in a Workshop in Bologna, but these papers best summarize the outcomes:
  - SIEBERT, B., TANNER, R., CHARTIER, J.-L., AGOSTEO, S., GROßWENDT, B., GUALDRINI, G., MÉNARD, S., KODELI, I., LEUTHOLD, G. & PRICE, R. 2006. Pitfalls and modelling inconsistencies in computational radiation dosimetry: lessons learnt from the QUADOS intercomparison. Part I: Neutrons and uncertainties. Radiation protection dosimetry, 118, 144-154.
  - PRICE, R. A., GUALDRINI, G., AGOSTEO, S., MÉNARD, S., CHARTIER, J.-L., GROßWENDT, B., KODELI, I., LEUTHOLD, G. P., SIEBERT, B. R. L., TAGZIRIA, H., TANNER, R. J., TERRISSOL, M. & ZANKL, M. 2006. Pitfalls and modelling inconsistencies in computational radiation dosimetry: lessons learnt from the QUADOS intercomparison. Part II: Photons, electrons and protons. Radiation Protection Dosimetry, 118, 155-166.

P4: Response of an albedo personal dosemeter

1. Model the neutron response by counting $^{6}Li(n, t)a$ events.
2. Assume that the neutron response is proportional to the number of capture reactions.
3. Calculate the fraction of the neutron response that is due to backscattered neutrons

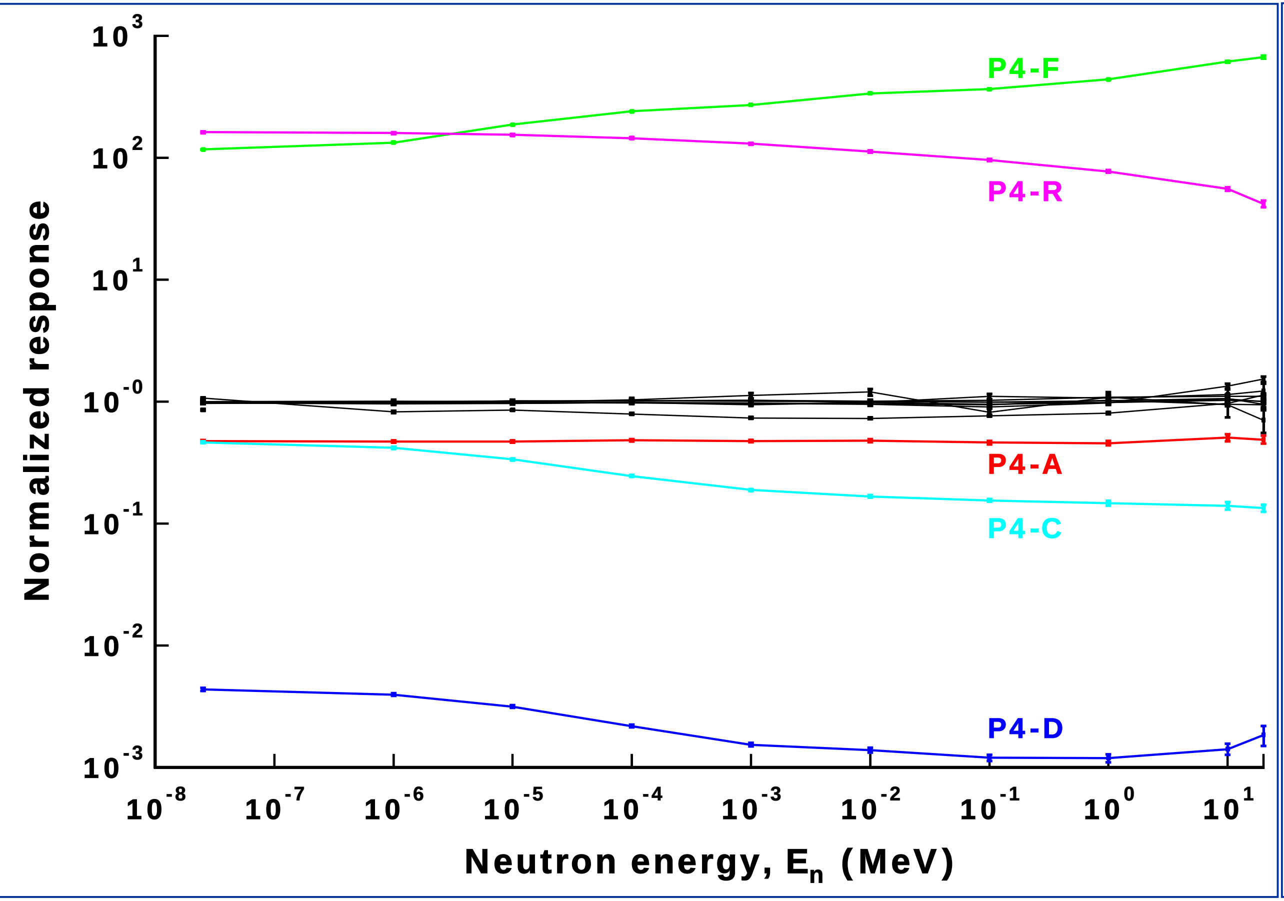




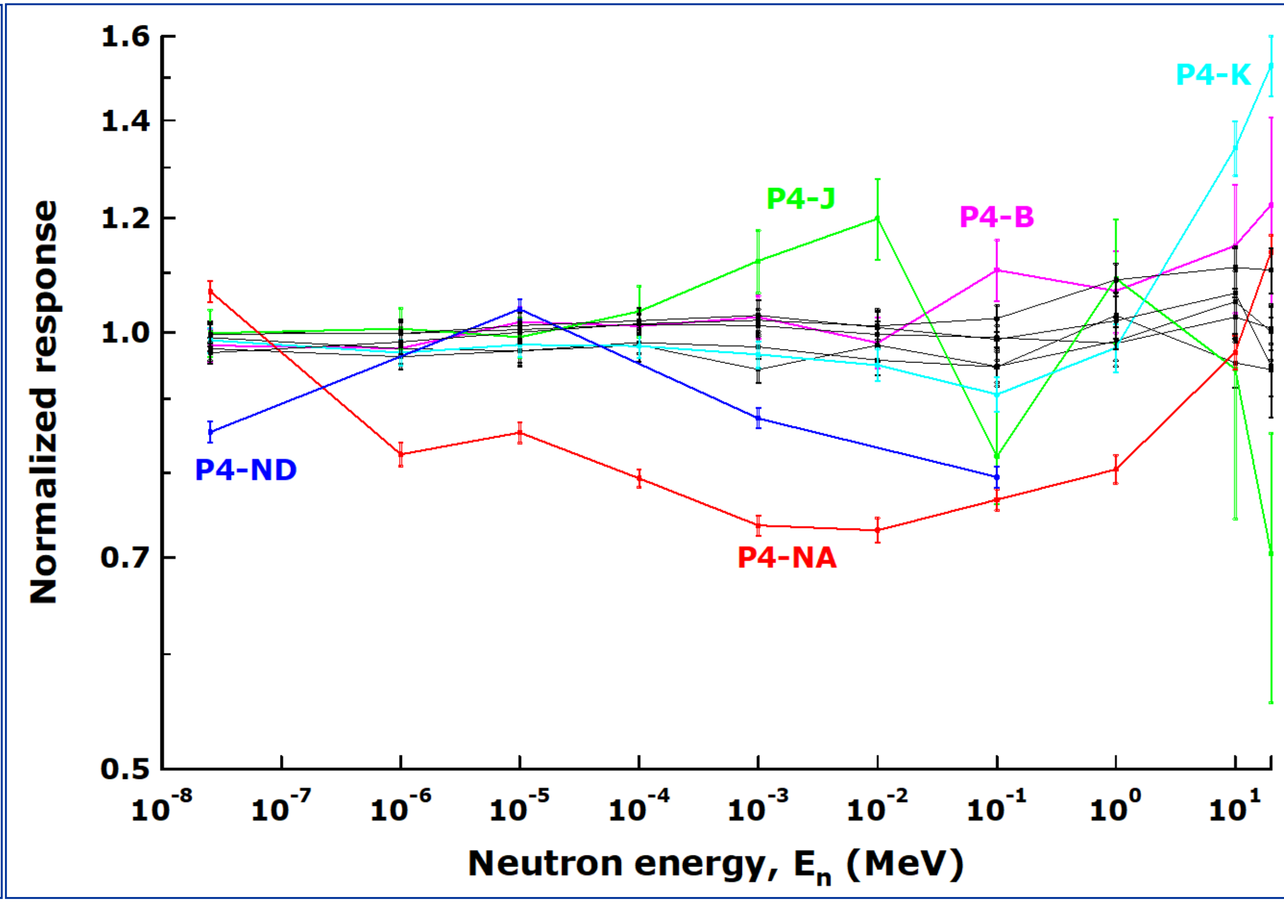
- 17 solutions
- 16 Monte Carlo
- 1 deterministic
- 15 participants transported photons
- 14 participants transported neutrons
- 13 solutions using MCNP family of codes
- 2 solutions using MCNPX
- One own code (photon only, but can transport n)
- One each TRIPOLI and PENELOPE

- 13 solutions from Europe
- 11 from EU
- France 4
- UK 3
- Austria, Greece, Italy Portugal 1 each
- 2 from Eastern Europe
- 3 from the US
- 1 from South America

P4: Normalized response for ^{6}LiF direct



All solutions



“Good” solutions – black in left hand figure

QUADOS: general conclusions

- The intercomparison drew solutions from a wide range of countries and areas of work
- Approximately 80 participants took part overall
- MCNP dominated amongst the codes used
- Agreement with the authors' solutions was in general very satisfactory
- Some solutions have large systematic errors
- Many participants required substantial help to get good agreement with the authors' solutions
- Statistical uncertainties were almost always quoted, but there was little other consideration of uncertainty

- FULL MEMBERS
- Gianfranco Gualdrini, ENEA, Italy (Chairman)
- Robert Price, City University, UK (Secretary)
- Bernd R. L. Siebert, PTB – Germany
- Bernd Grobwendt, PTB – Germany
- Maria Zankl, GSF – Germany
- Jean Louis Chartier, – France
- Michel Terrissol, CPAT-Toulouse – France
- Loic de Carlan, CEA-Saclay France
- Rick Tanner, HPA – UK
- Ivo Kodeli, NEA-DB France
- Stefano Agosteo, Politecnico Milano – Italy
- Jean Marc Bordy, CEA – Saclay – France
- Jose Maria Gomez Ros, – CIEMAT - Spain
- Sofia Rollet, ARCS Austria
- Frank Schultz, TU Delft – The Netherlands

CONRAD WP4 Computational Dosimetry

- WG6 became WP4 for the CONRAD period
- Stochastic Uncertainties only
  - P1 Proton Recoil Telescope
  - P2 Bonner Sphere Spectrometer
  - P3 SIGMA neutron field
- Expressing overall uncertainty
  - P4 Photon irradiation facility
  - P5 Manganese Bath
  - P6 Iron sphere experiments
  - P7 Energy response of a RADFET
  - P8 Recoil proton telescope

CONRAD WP4 Activities & Cross-collaborations

WP4 Computational dosimetry:

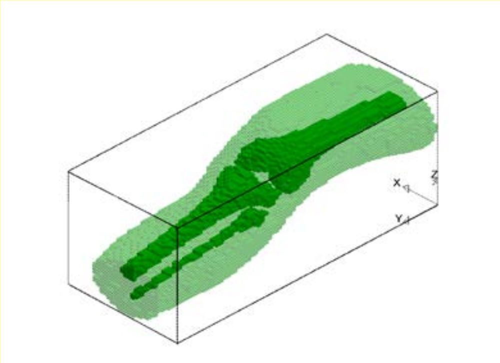
8 standard problems with experimental data

3- only with stochastic uncertainties

5- with overall uncertainty budget estimate

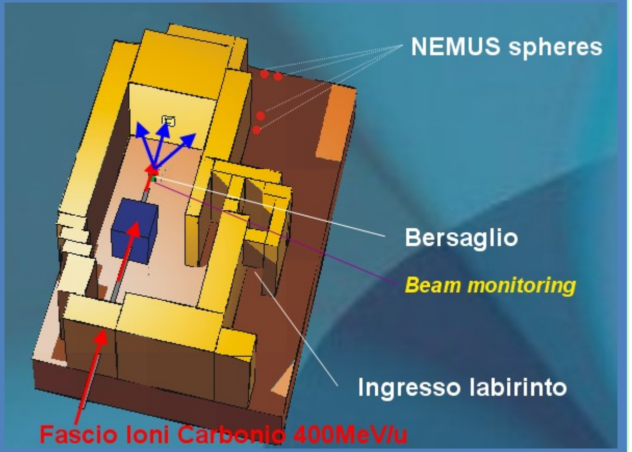
WP5 Internal dosimetry:

Knee phantom for in vivo measurements of actinides



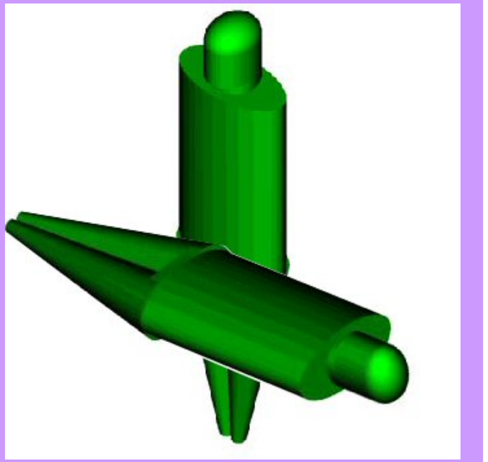
WP6 Complex radiation fields:

Neutron spectra MC evaluation outside a carbon ion beam bunker (GSI)



WP7 Medical staff dosimetry:

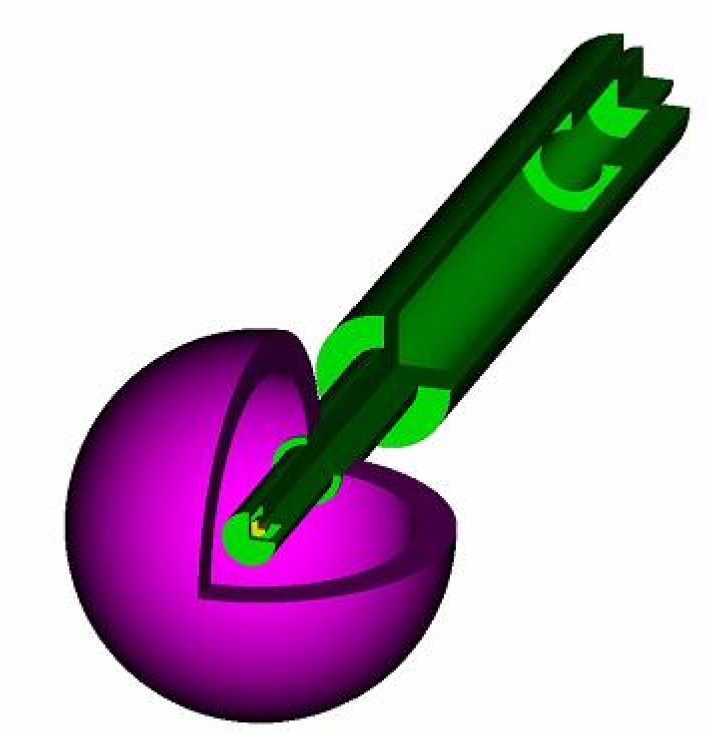
Occupational dose evaluation for medical staff during cardiac interventional procedures

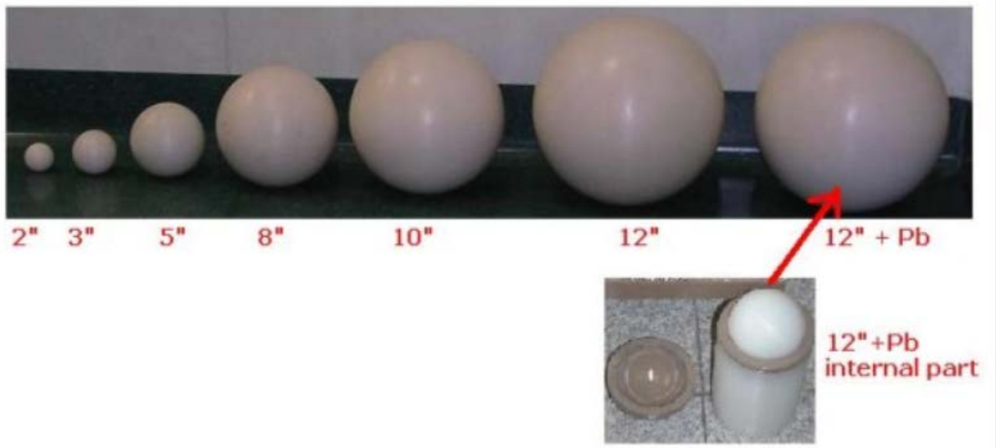


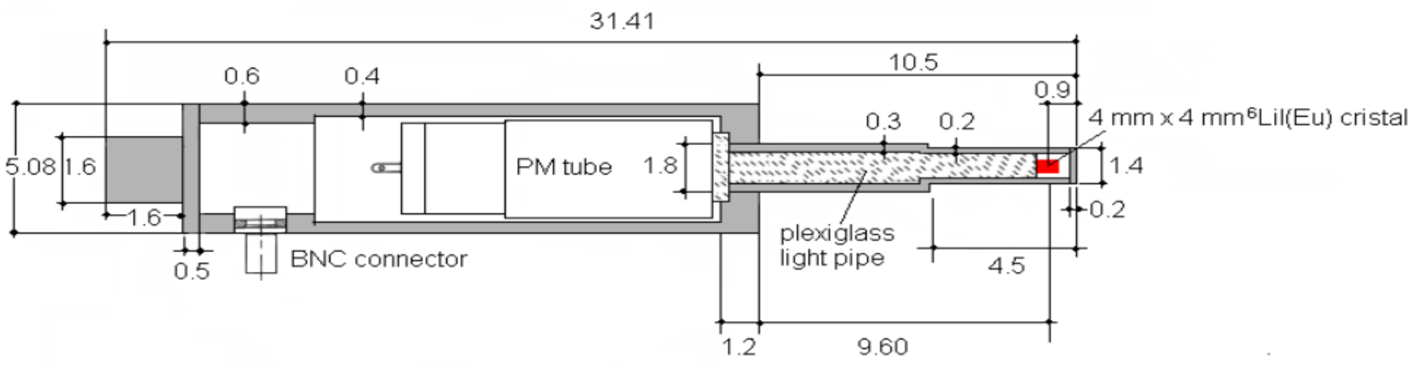
P2 Problem Summary: **Bonner Sphere Spectrometer**

G. Gualdrini, R. Bedogni and P. Ferrari

AIM OF THE STUDY: study the response of a widespread neutron spectrometer exposed to the ISO standard neutron sources ^{241}Am-Be and ^{252}Cf







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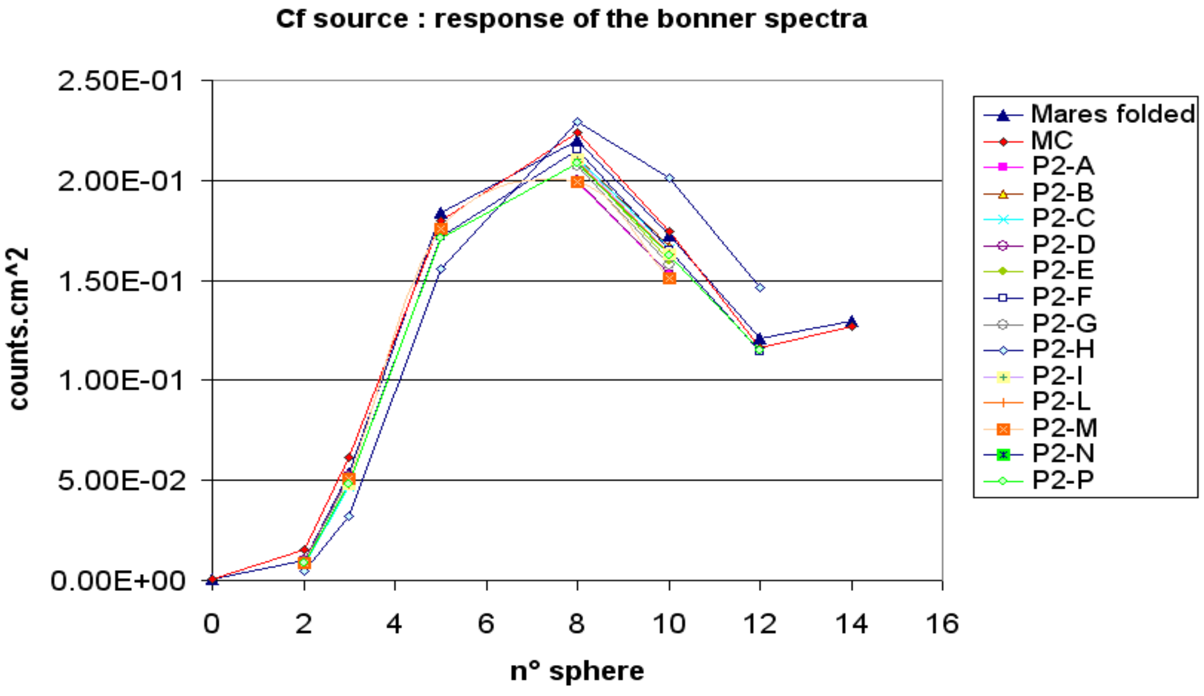

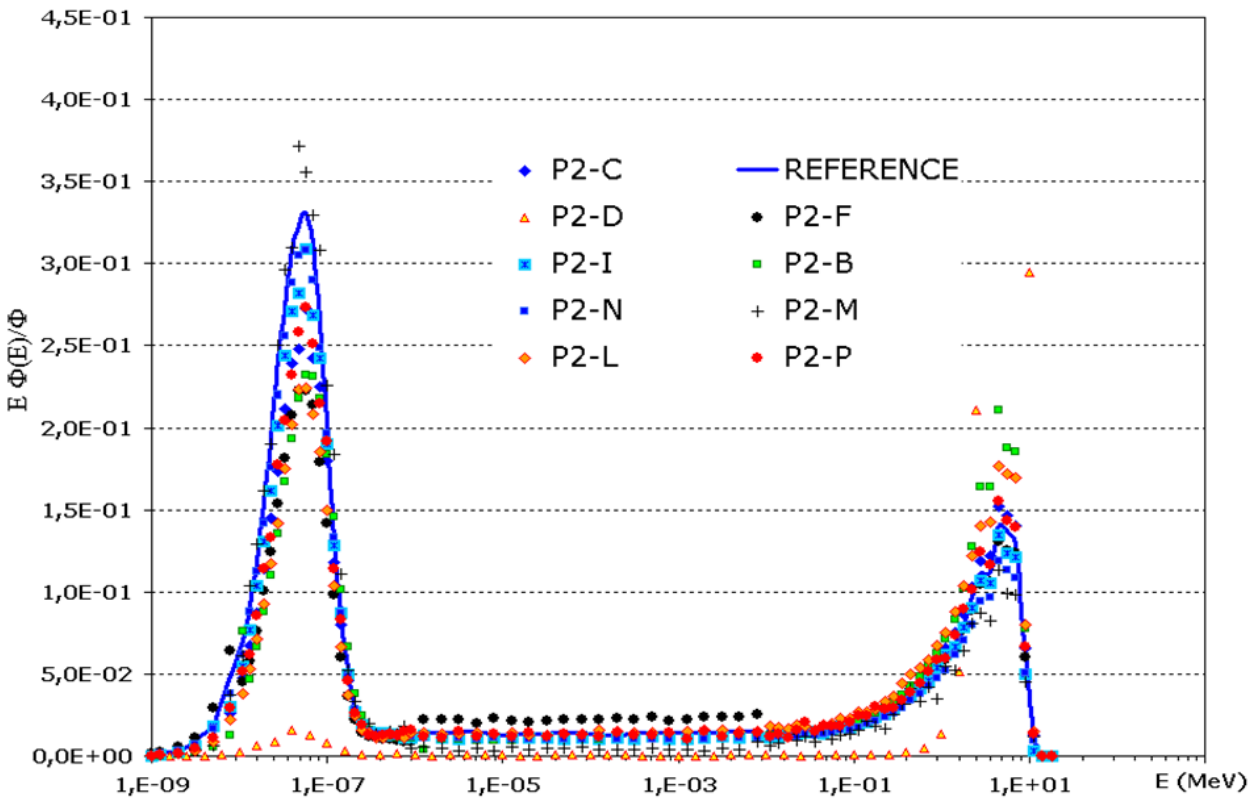

Unfolded spectra

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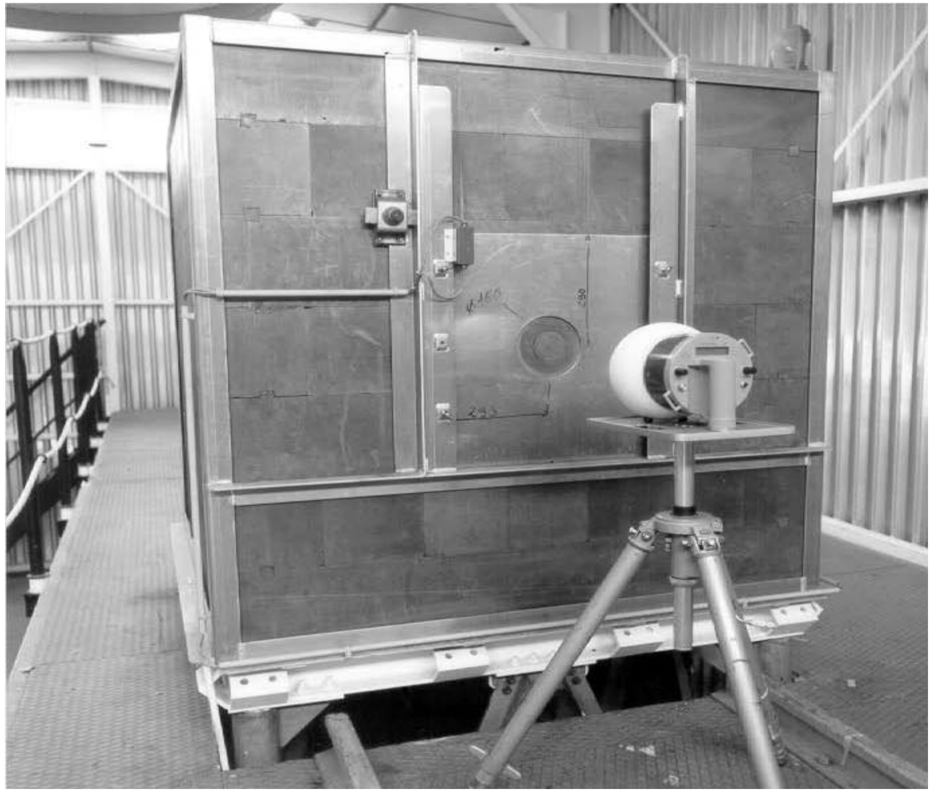
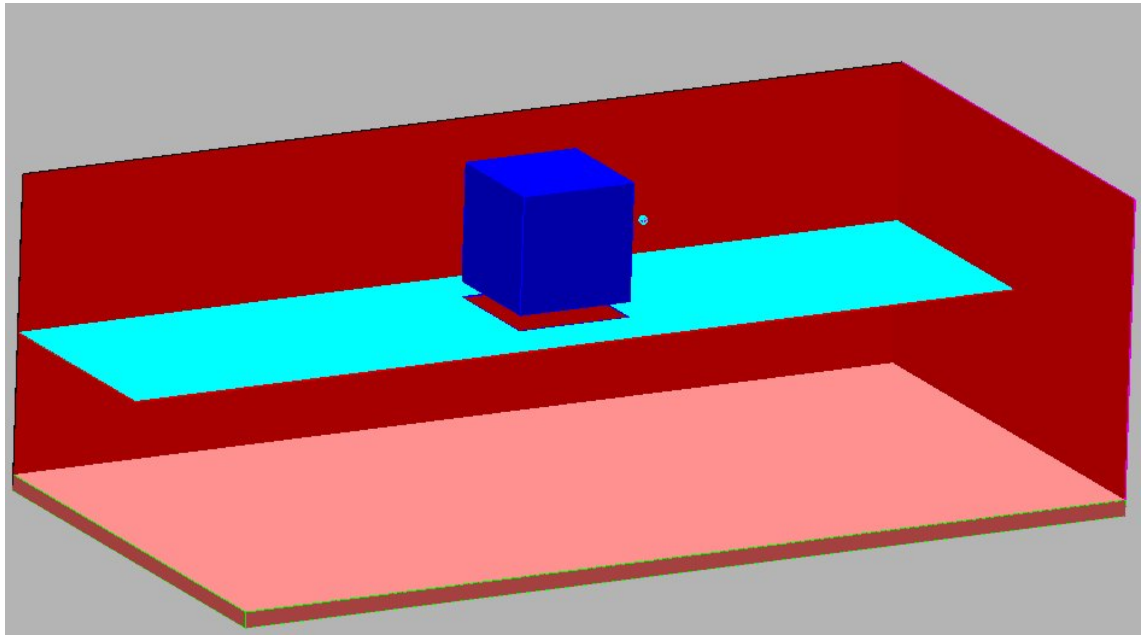
P3 SIGMA: thermalized neutron field

Rick Tanner & Veronique Lacoste





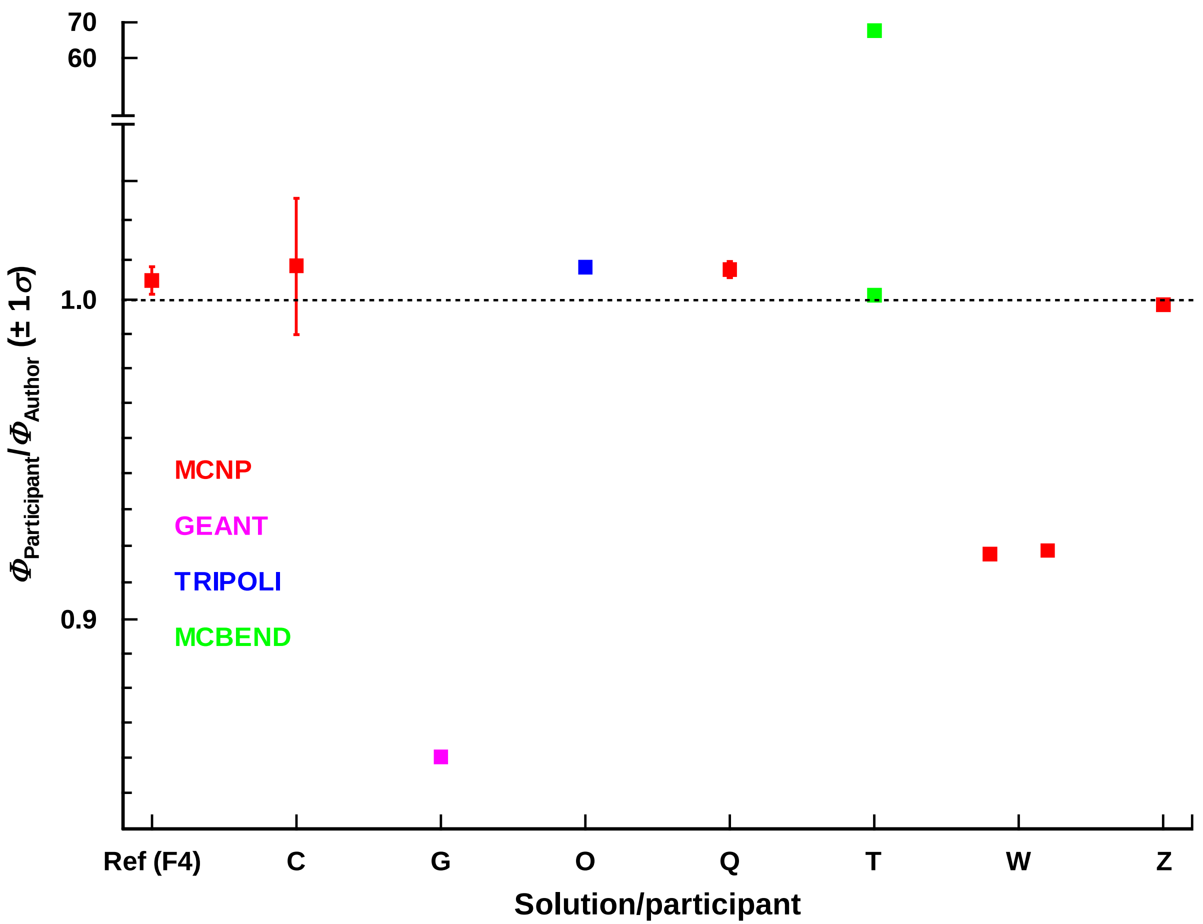
Located at IRSN, Cadarache, France

Six 0.6 TBq ^{241}Am-Be sources in a 1.5 m^3 graphite block

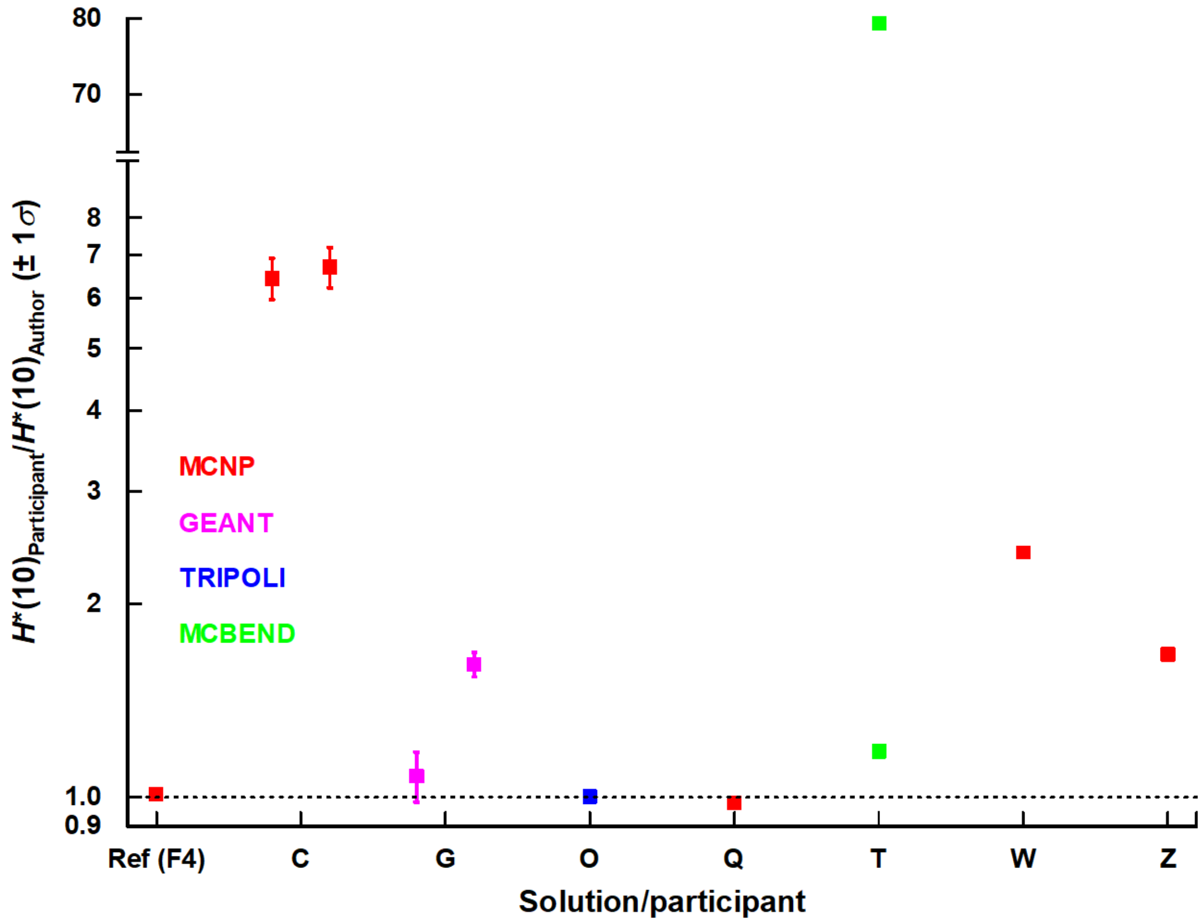
Elastic scattering in graphite (low capture cross-section) thermalizes field

P3 SIGMA: thermalized neutron field

Rick Tanner & Veronique Lacoste



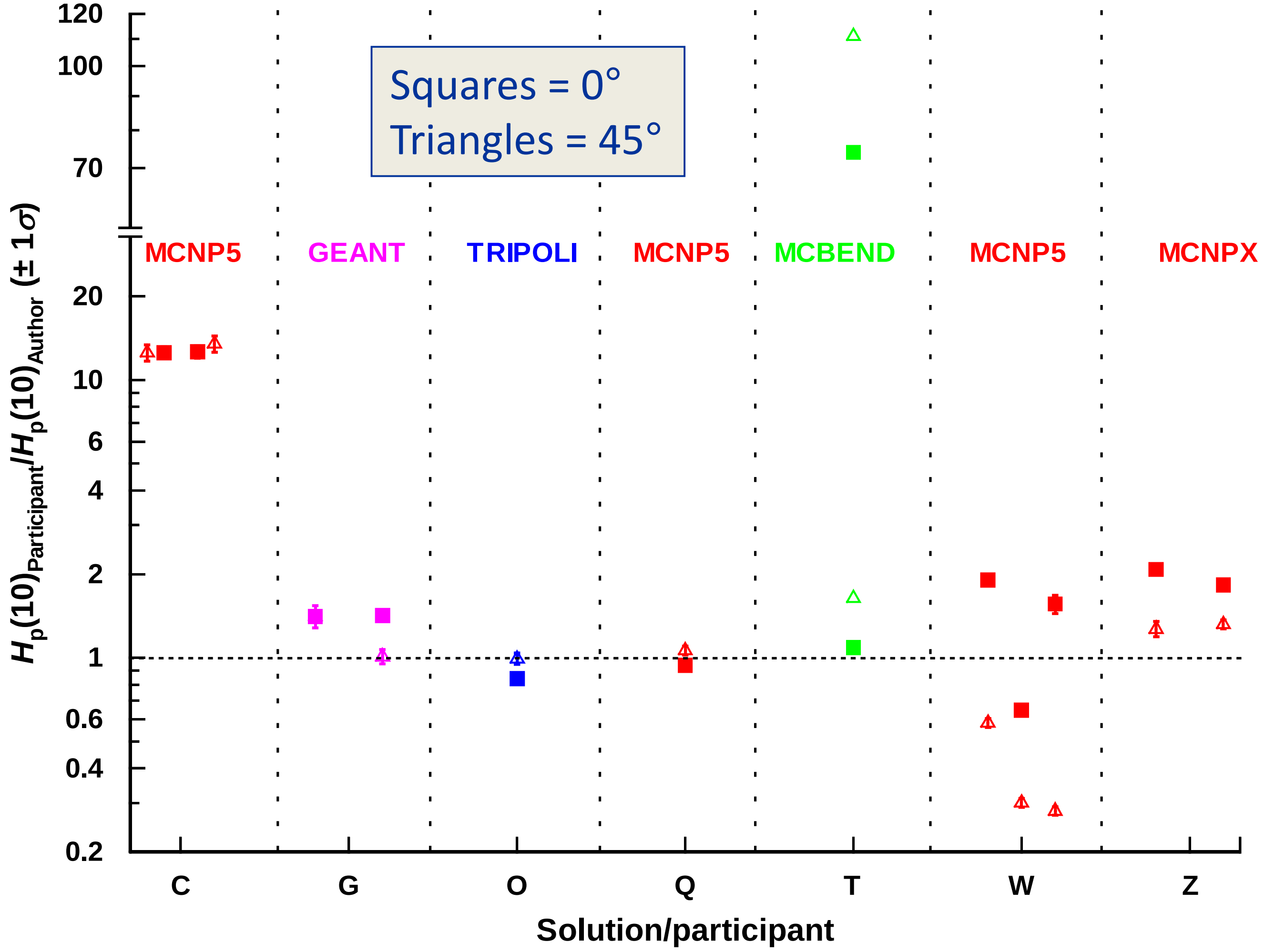
Total fluence results (T allowed to correct solution)



*H**(10) results (T allowed to correct solution)

P3 SIGMA: thermalized neutron field

Rick Tanner & Veronique Lacoste



- $H_p(10)$ results
- Calculated directly in a slab phantom
- Some:
  - good solutions
  - needed a chance to correct
  - Unresolved issues

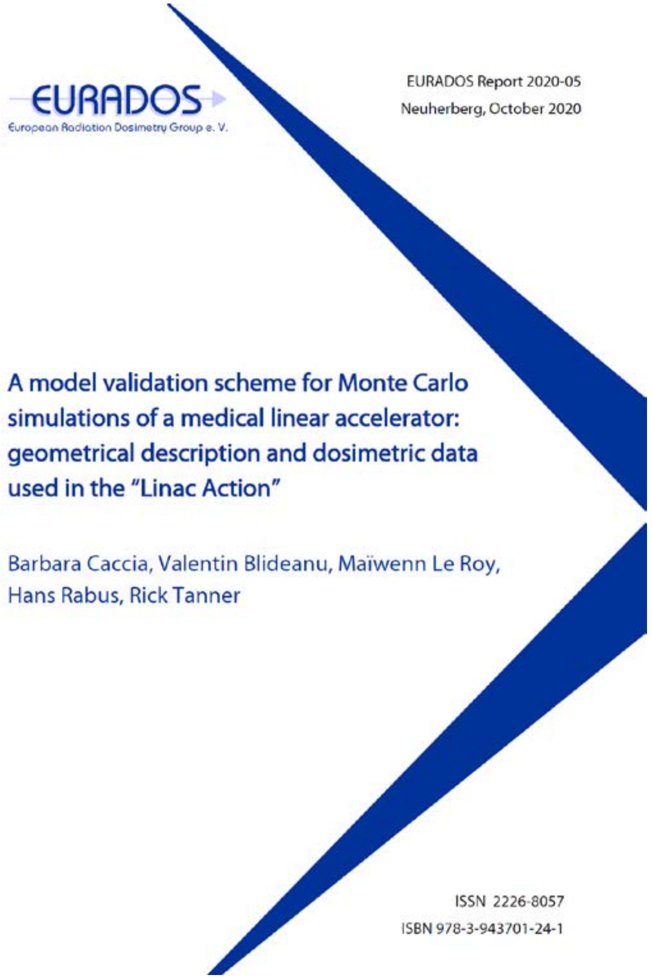
CONRAD: general conclusions

- The problem set was much more demanding
  - We could not have asked participants to take on such difficult tasks at the time of QUADOS
  - Not trivial for the “authors” to determine the reference solutions!
- The dominance of MCNP family of codes was becoming more significant
- Still many (very) poor solutions
- All problems could be solved well by some participants

WG6 Intercomparions – notable omissions…

- WG6 has performed several exercises with other WGs that are not reported here due to lack of time! Notably:
  - Internal dosimetry problems with WG7 Internal Dosimetry
    - Vrba, T. et al 2014. EURADOS intercomparison exercise on MC modeling for the in-vivo monitoring of Am-241 in skull phantoms (Part I). Radiat. Phys. Chem. 104, 332–338.
    - Vrba, T. et al 2015. EURADOS intercomparison exercise on MC modelling for the in-vivo monitoring of AM-241 in skull phantoms (Part II and III). Radiat. Phys. Chem. 113, 59–71.
  - Bonner sphere unfolding with WG11 High energy fields
    - Refs to be added for online posting!

WG6 Intercomparions – Linac Modelling



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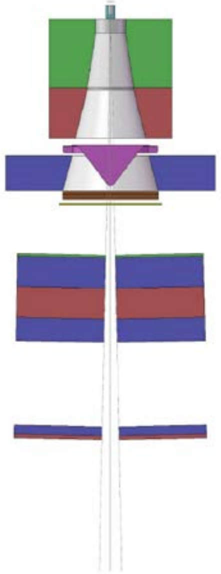
European Radiation Dosimetry Group e. V.

EURADOS Report 2020-05
Neuherberg, October 2020

A model validation scheme for Monte Carlo simulations of a medical linear accelerator: geometrical description and dosimetric data used in the "Linac Action"

Barbara Caccia, Valentin Blideanu, Maïwenn Le Roy, Hans Rabus, Rick Tanner

ISSN 2226-8057
ISBN 978-3-943701-24-1



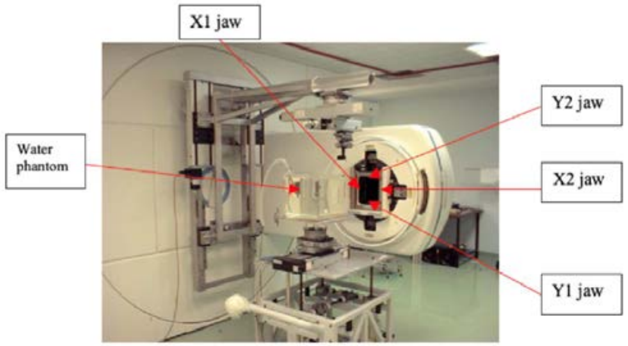


Fig. 1: A general view of the geometry of the Saturn 43 linear accelerator and the water phantom

- Complex model which looked at dose deposition in a phantom
- Full report downloadable from the EURADOS website

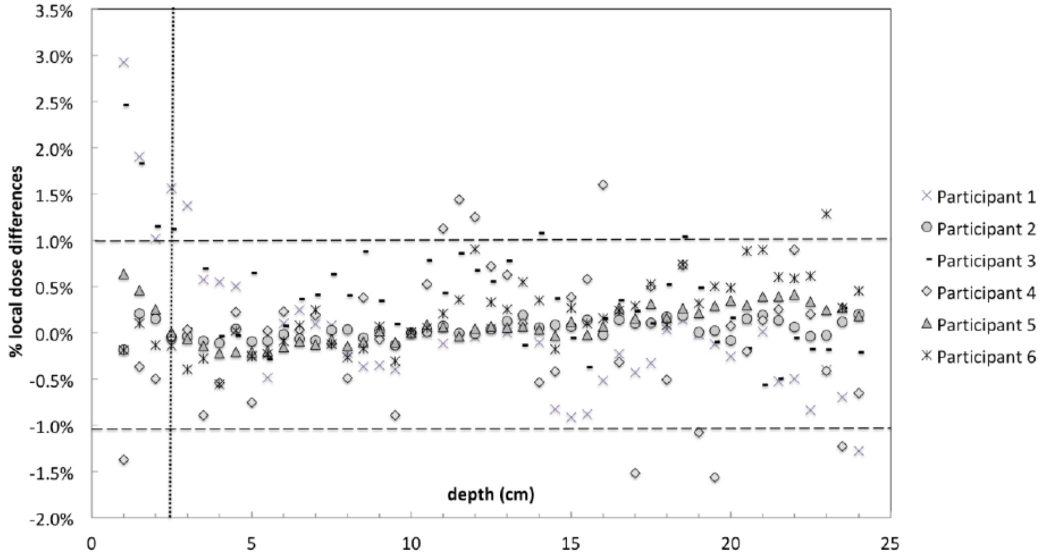


Fig. 21: Percentage of the local dose differences between calculated and measured doses (PDD) in a water phantom for the six participants. The dashed lines represent the ±1% dose-difference region and the dotted line indicates the depth of the build-up region.

Recent intercomparisons

- **WG6 has recently been running intercomparisons using problems that would have been far too complex in the past**
  - **Neutron spectrum unfolding** using Monte Carlo to generate the fields
  - **Micro & nano dosimetry** at scales which could not previously have been considered
  - **Fetal dose in proton therapy**
  - **Voxel phantom** problems – perhaps the benefit of WG6 Voxel Schools that so many can now do these
- **Special edition of Radiation Measurements about to be published**

Voxel phantom intercomparison – ^{60}Co point source – initial data

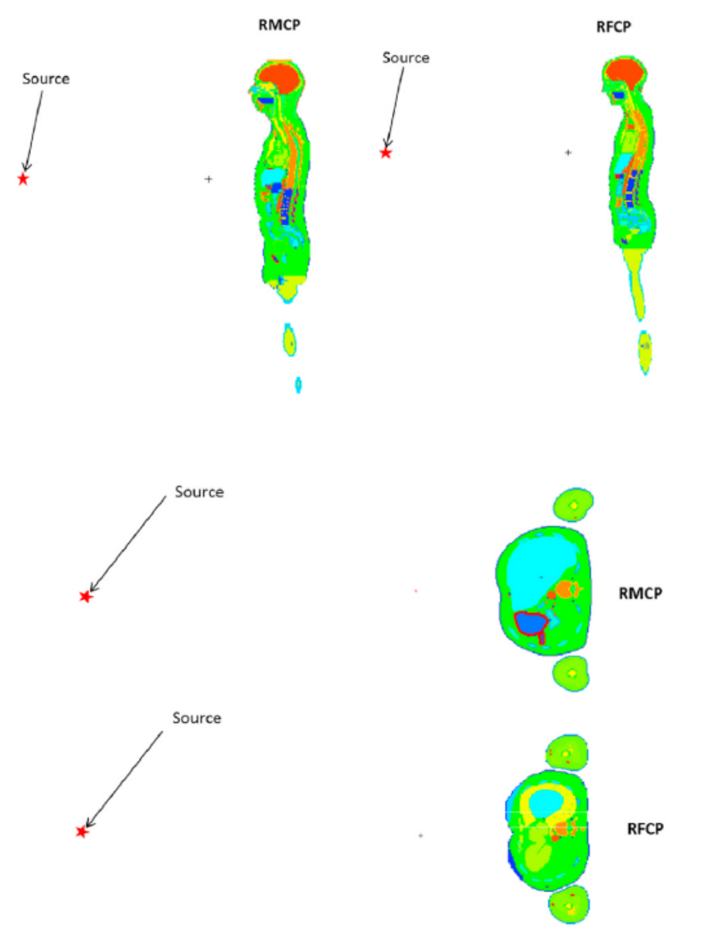
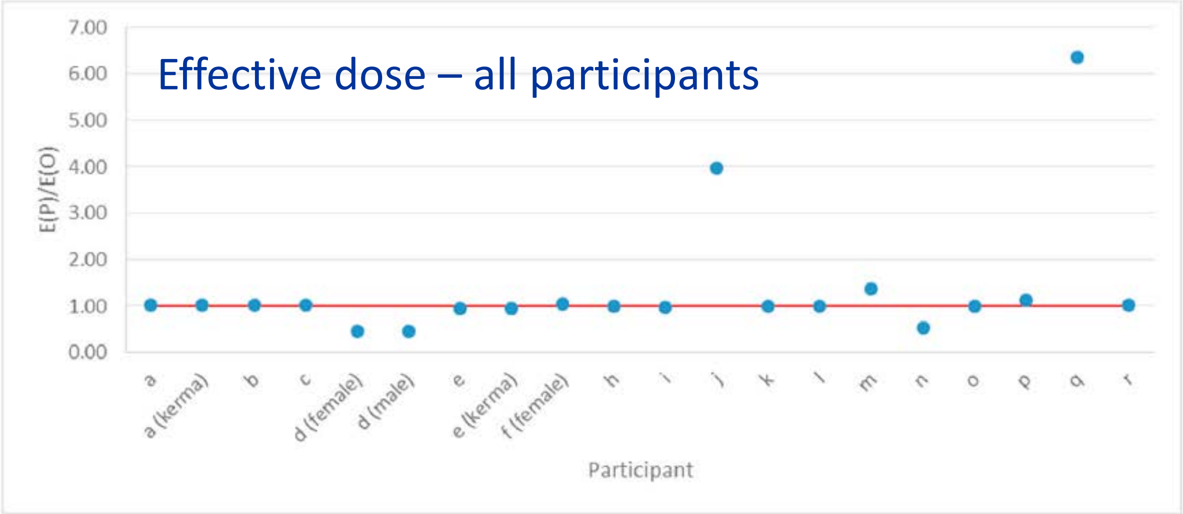
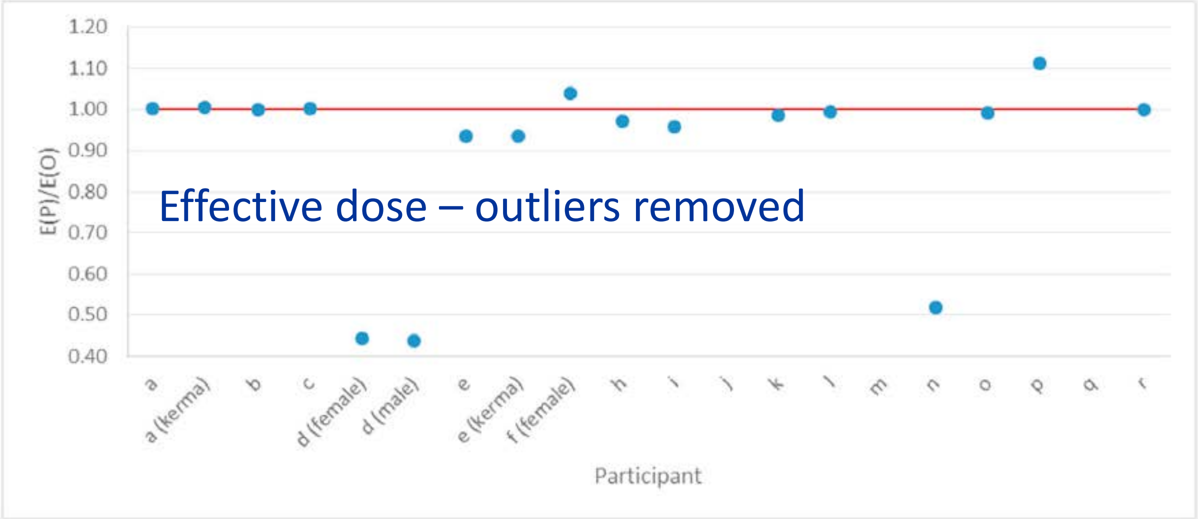


Fig. 1. Illustration of point source position relative to RMCP (male) and RFCP (female) phantoms.





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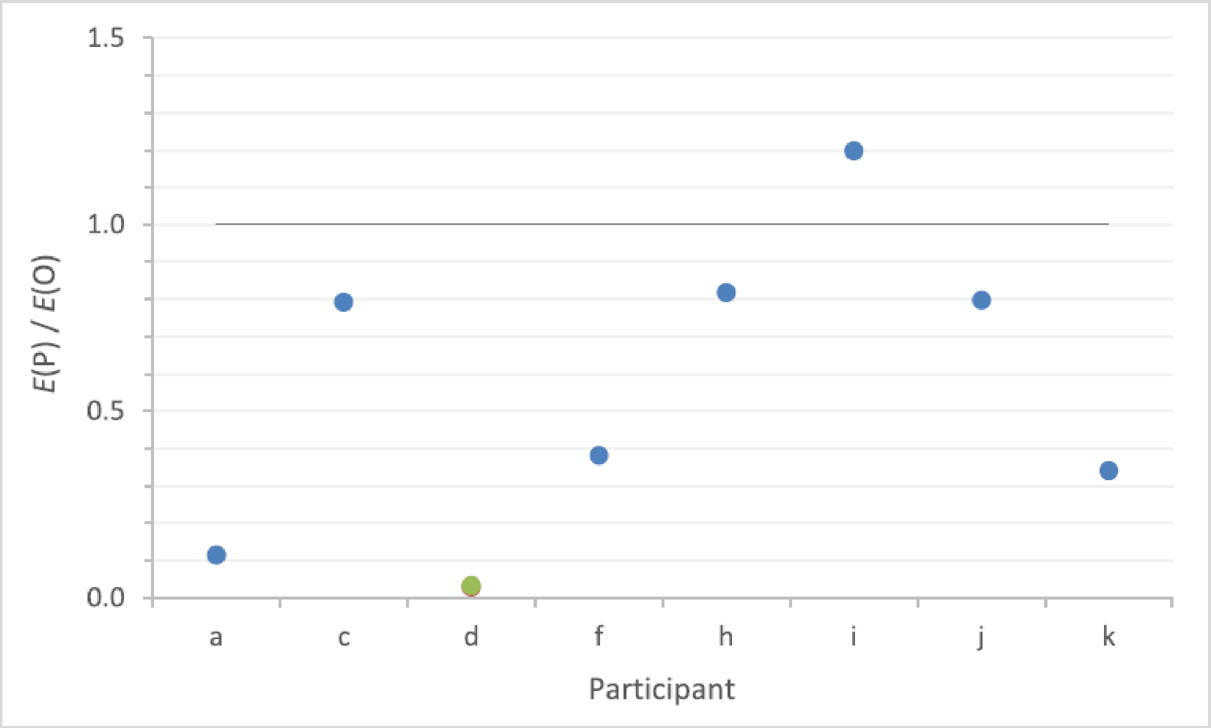
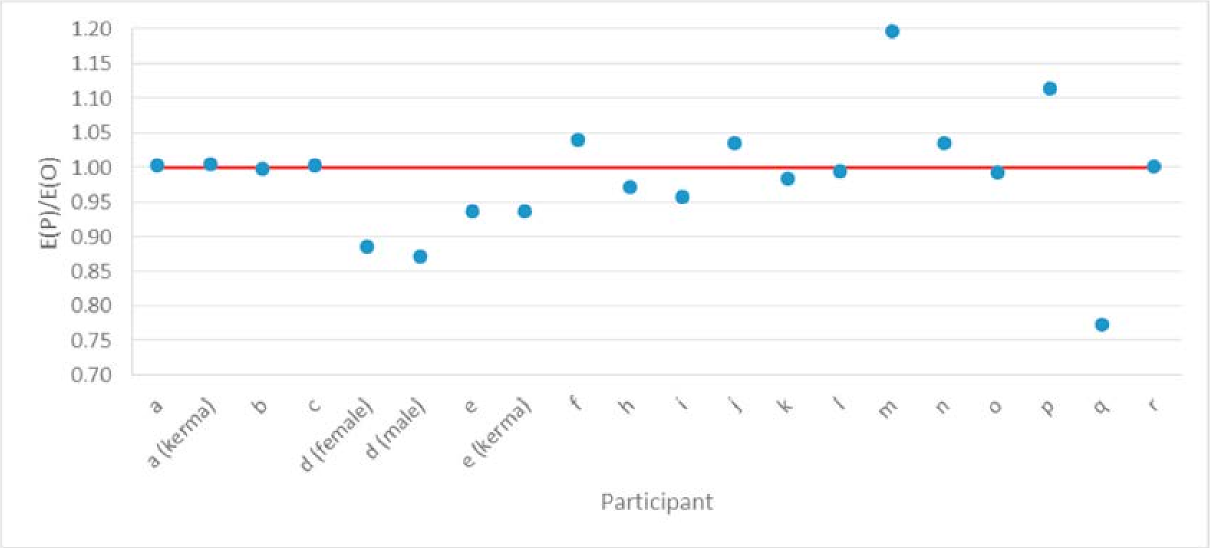
Voxel phantom intercomparison – ^{60}Co (revised), 10 keV neutrons



Neutron effective dose



Photon effective dose after participants revised solutions

Voxel phantom intercomparisons – chest x-rays

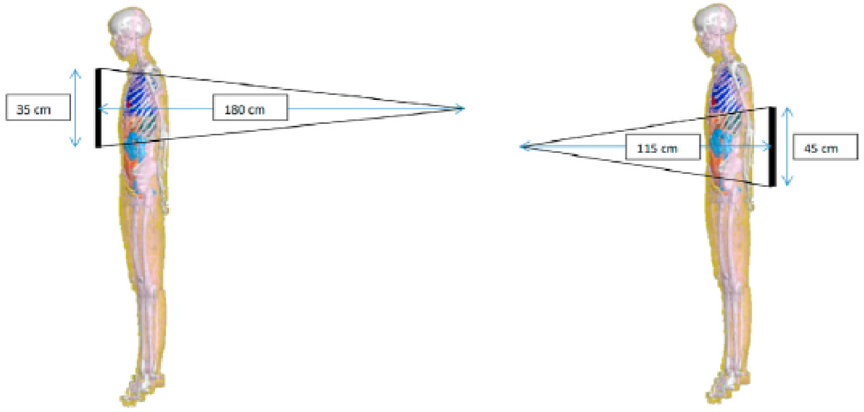
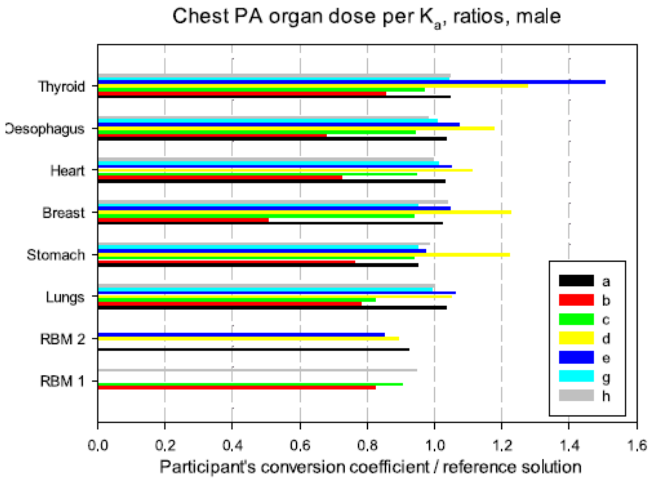
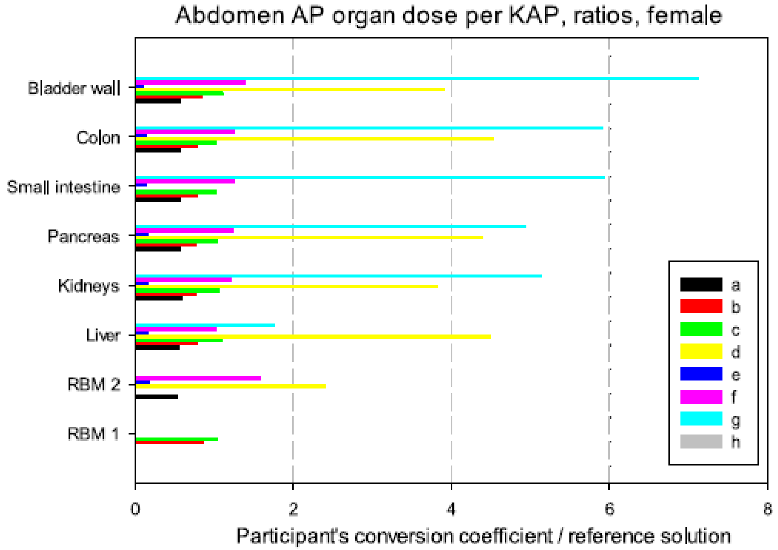
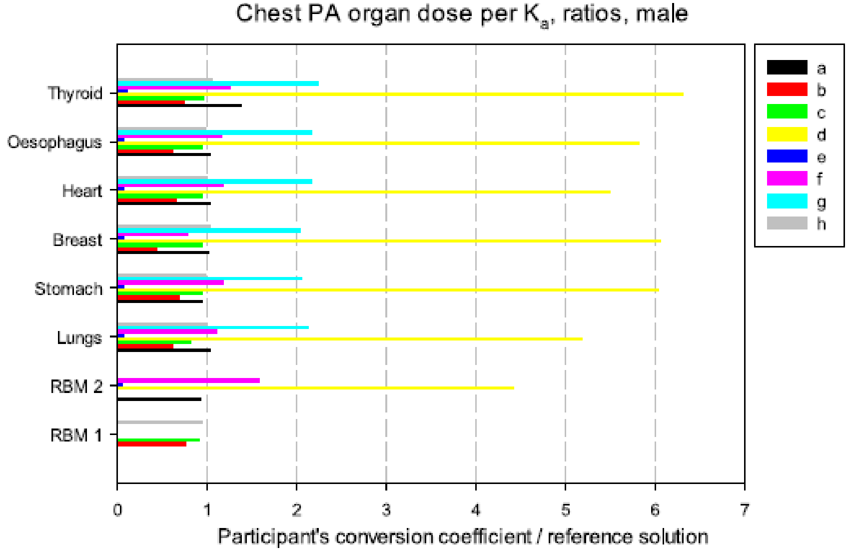


Fig. 2. PA chest (left) and AP abdomen (right) examinations.







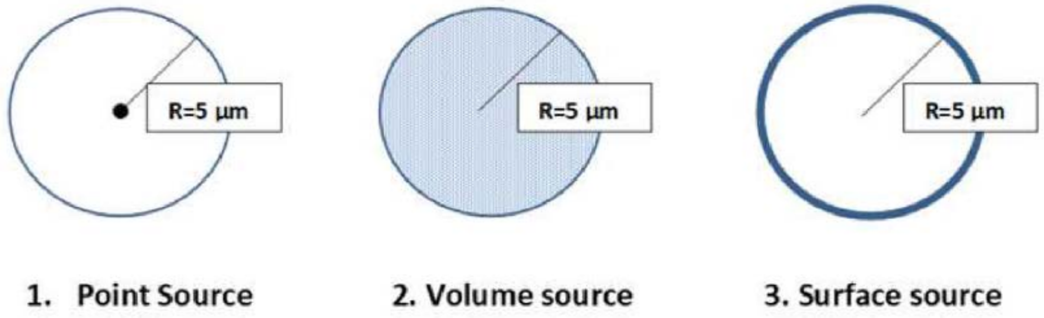
Voxel phantom intercomparisons – other work papers…

- Eakins, J. et al 2021. Monte Carlo calculation of organ and effective dose rates from **ground contaminated by Am-241**: Results of an international intercomparison exercise
- Gómez-Ros et al 2021. Monte Carlo calculation of the organ equivalent dose and effective dose due to **immersion in a ^{16}N beta source in air** using the ICRP reference phantoms. Radiat. Meas. 145
- Huet, C. et al 2022. Monte Carlo calculation of organ and effective doses due to photon and neutron point sources and typical X-ray examinations: Results of an international intercomparison exercise. Radiat. Meas. 150
- Zankl, M. et al 2021a. The ICRP recommended methods of **red bone marrow dosimetry**. Radiat. Meas. 146, 106611. https://doi.org/10.1016/j.radmeas.2021.106611
- Zankl, M. et al 2021b. EURADOS intercomparison on the usage of the ICRP/ICRU adult reference computational phantoms. Radiat. Meas. 145, 106596. https://doi.org/10.1016/j.radmeas.2021.106596
- Zankl, M. et al 2021c. Monte Carlo calculation of organ dose coefficients for internal dosimetry: Results of an international intercomparison exercise. Radiat. Meas. 148, 106661. https://doi.org/10.1016/j.radmeas.2021.106661

Micro and nano dosimetry

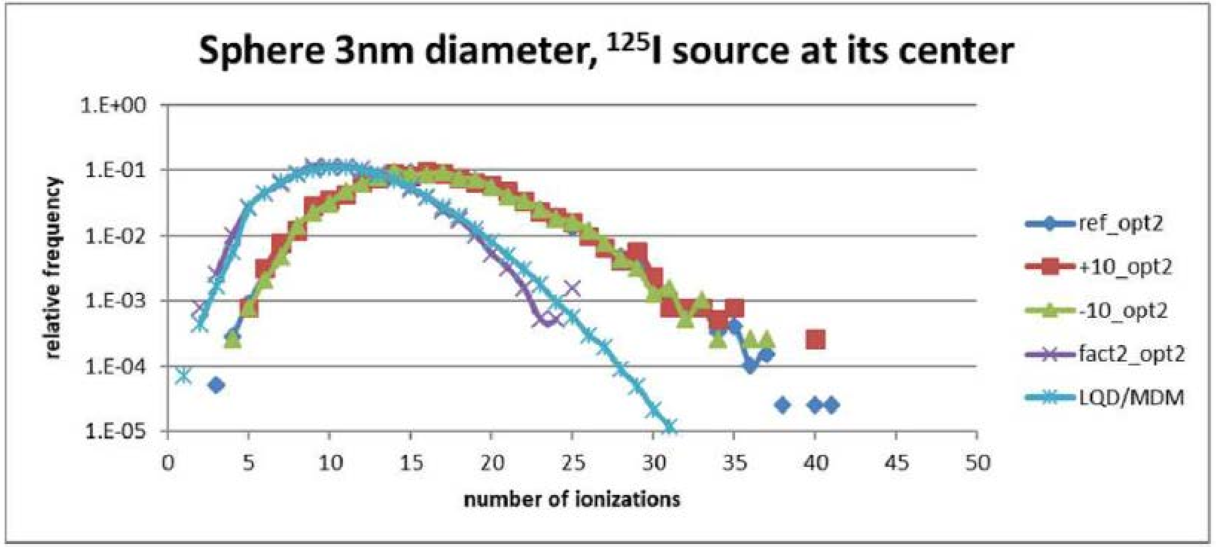
- These calculations have long been a part of the WG6 work programme, via the work of Michel Terrisol, now retired
- However, recent code developments have made these calculations much more feasible
- The accurate transport of low energy electrons is imperative, especially where there are material inhomogeneities
    - Typical examples are high *Z* nanoparticles
- Uncertainties are a big issue in this energy range, because of cross-section uncertainties

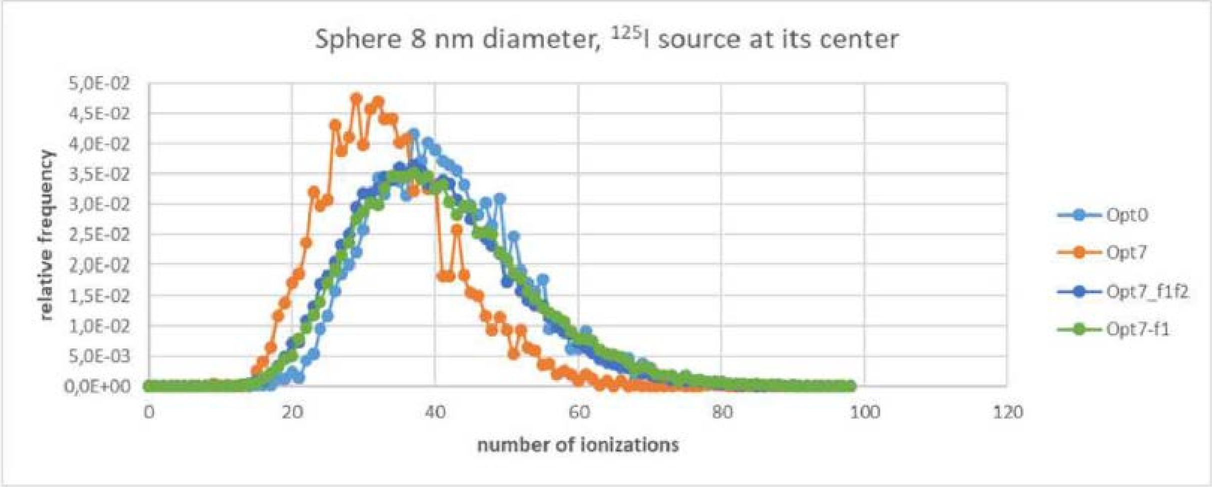
Micro & Nano Dosimetry Intercomparison



Full analysis:

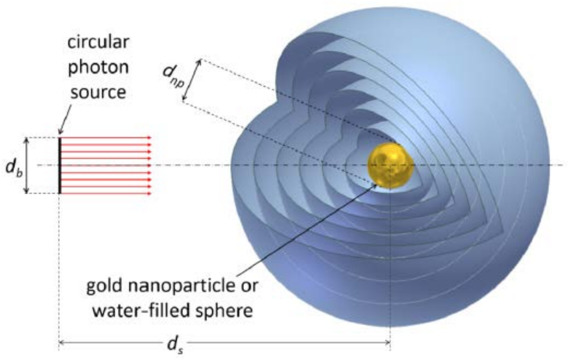
- Villagrasa, C. et al 2022. Intercomparison of micro- and nanodosimetry Monte Carlo simulations: An approach to assess the influence of different cross-sections for low-energy electrons on the dispersion of results. Radiat. Meas. 150

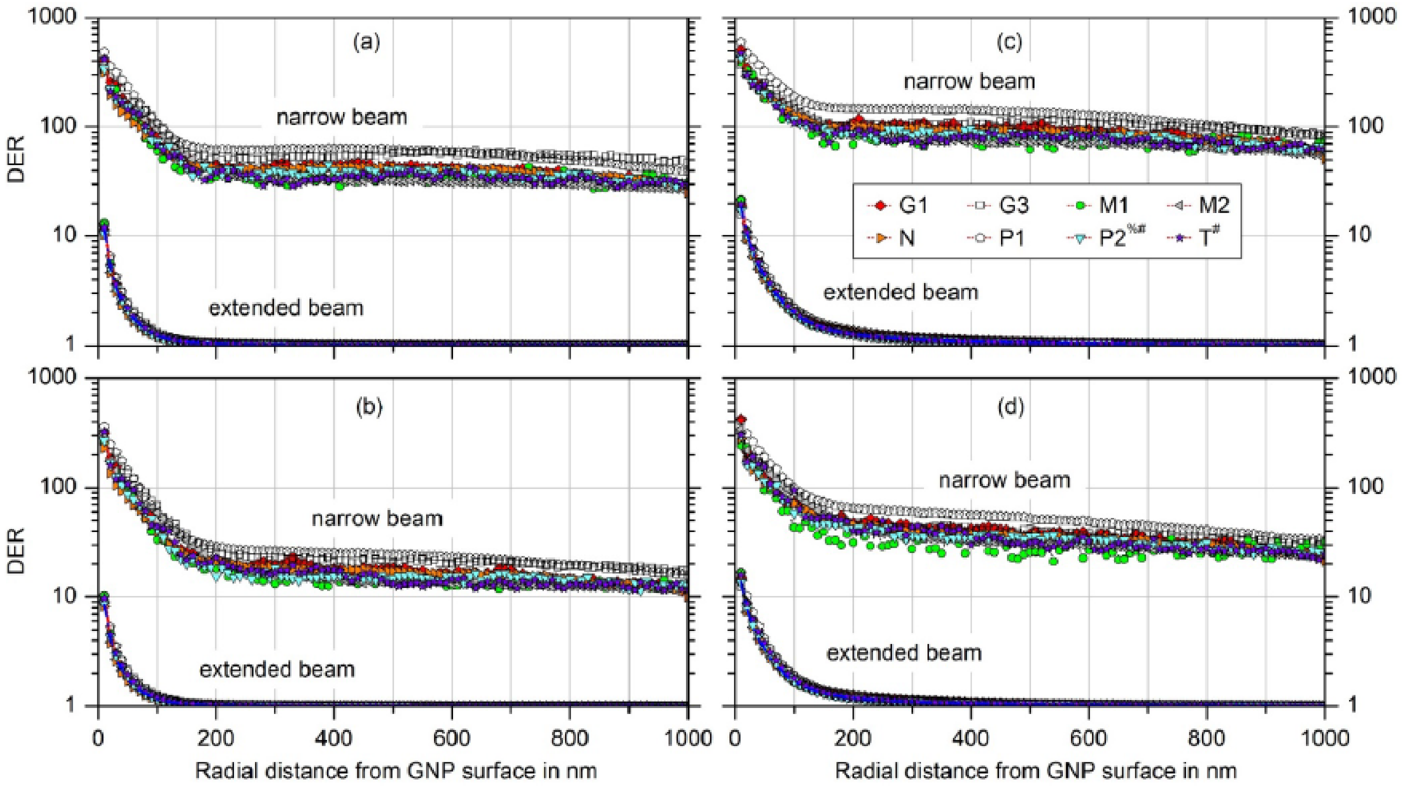




Micro and nano dosimetry – gold nanoparticles (with WG7)

- Intercomparisons on nanoparticle effect on dose deposition
- High *Z* materials enhance photoelectric effect
- Lot of low energy, short range electrons





Neutron spectrum unfolding

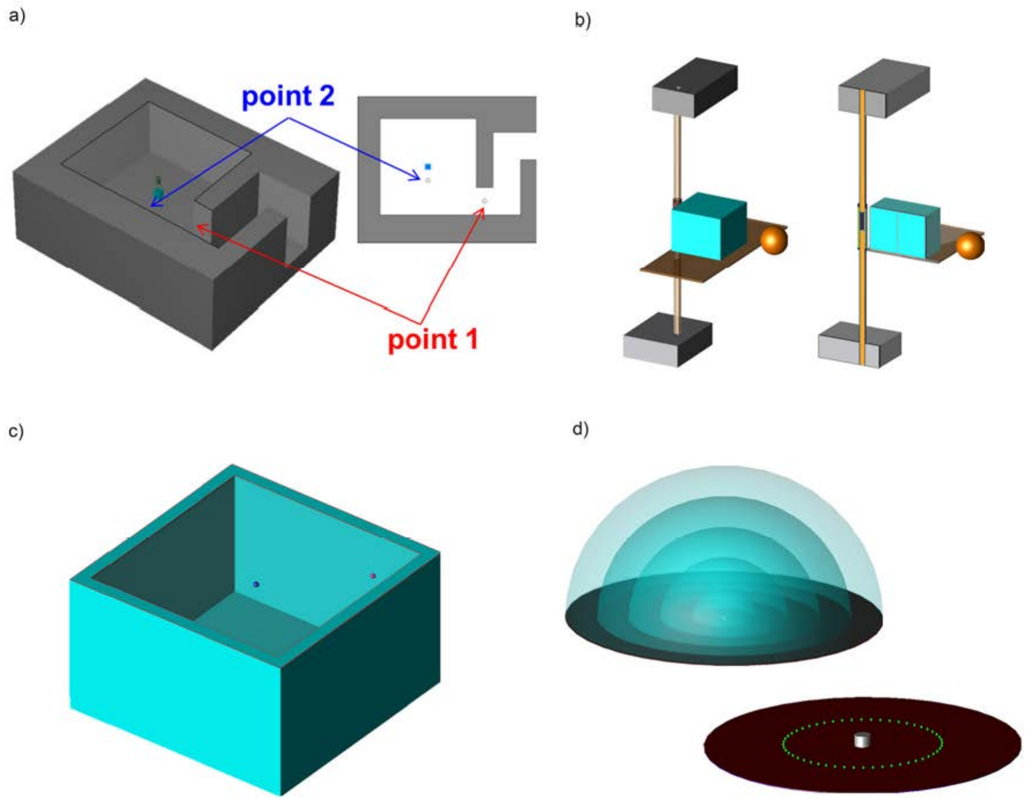


Figure 2: Irradiation scenarios: a) medical LINAC (2 measurement points); b) workplace; c) calibration facility; d) skyshine.

- **Started with neutron unfolding and now finishing with it**
- **Purely Monte Carlo solutions**
  - Gómez-Ros, J.M., Bedogni, R., Domingo, C., Eakins, J.S., Roberts, N., Tanner, R.J., 2022. Results of the EURADOS international comparison exercise on neutron spectra unfolding in Bonner spheres spectrometry. Radiat. Meas. 153, 106755.
  - Gómez-Ros, J.M., Bedogni, R., Domingo, C., Eakins, J.S., Roberts, N., Tanner, R.J., 2018. International comparison exercise on neutron spectra unfolding in Bonner spheres spectrometry: problem description and preliminary analysis. Radiat. Prot. Dosimetry 180, 70–74.

Neutron spectrum unfolding

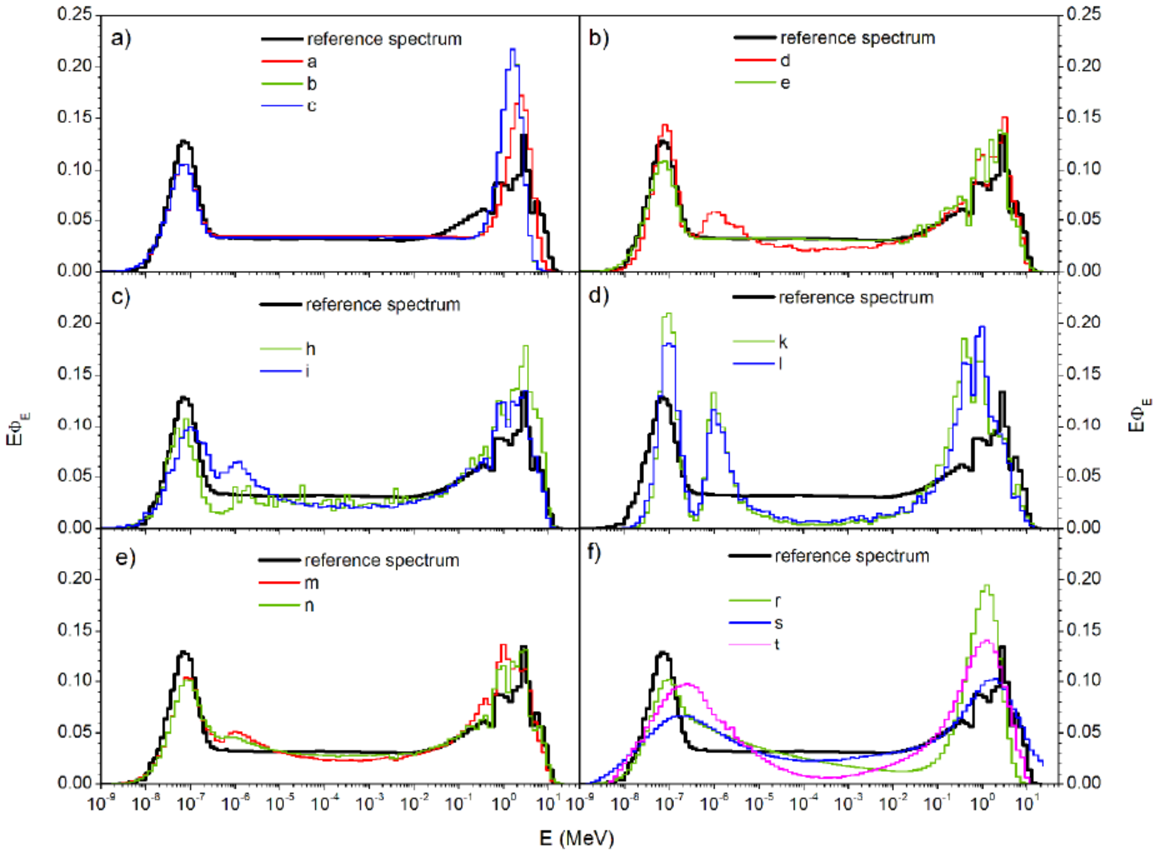


Figure 7: Participants unfolded spectra (in colour) compared with the reference spectra for the skyshine scenario.

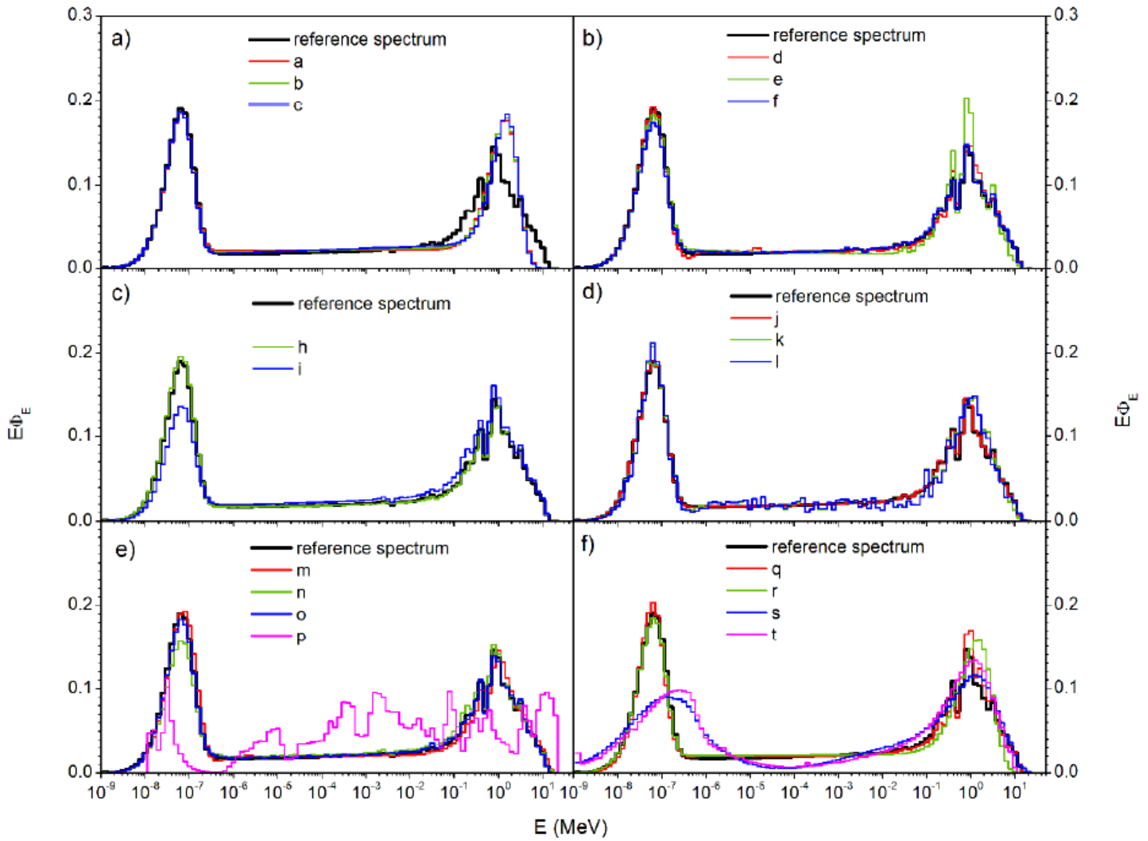


Figure 6: Participants unfolded spectra (in colour) compared with the reference spectra for the calibration facility.

Concluding remarks

- The ongoing programme of intercomparisons in computational dosimetry is seen to be an important:
  - Test of how well numerical methods are applied in practice
  - A valuable training tool
- The solutions have always been mostly "good"
- However, there are, as ever, solutions that can easily be improved with dialogue with the participant
- But:
  - there are still big outliers which cannot be resolved
  - the problems set have got a lot harder
  - the codes and computing power available have improved a lot

Concluding remarks

- Should we try to follow the personal/area dosemeter example of developing pass categories
  - Hard to specify pass criteria – but we can try?
  - Levels A, B and C?
- Could we then issue certificates to participants to verify their success?
- Perform regular (annual) intercomparisons:
  - With a fee?
- To give some sort of accreditation for Computational Dosimetrists analogous to that provided by EN ISO/IEC 17025:2017 which requires independent assessments of performance?