P3 - SIGMA

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Geometry

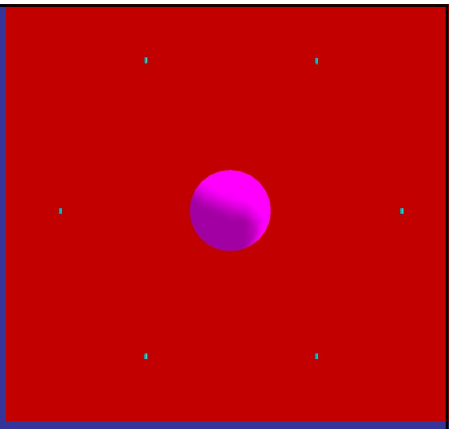
- "Thermal" neutron calibration source
- Uses a 1.5x1.5x1.5 m^3 block of pure graphite - 1.7 g cm^{-3}
- Six 0.6 TBq ^{241}Am-Be sources embedded in the graphite
- Hall 6 m wide, 12 m long and 4.5 m high
- 5 cm thick walls: glass wool layer between two aluminium plates
- Graphite base 2 m above concrete floor

Geometry

- Six 0.6 TBq ^{241}Am-Be sources in a hexagonal pattern within the graphite
- Sources in the horizontal plane, 25 cm from the centre of the graphite block
- Emission rate based on manganese bath measurements made in 1968
- Emission rate = (1.9071 ± 0.0414) x 10^{8} s^{-1} in 4π
- Hall 6 m wide, 12 m long and 4.5 m high
- 5 cm thick walls: glass wool layer between two Al plates
- Graphite base 2 m above concrete floor

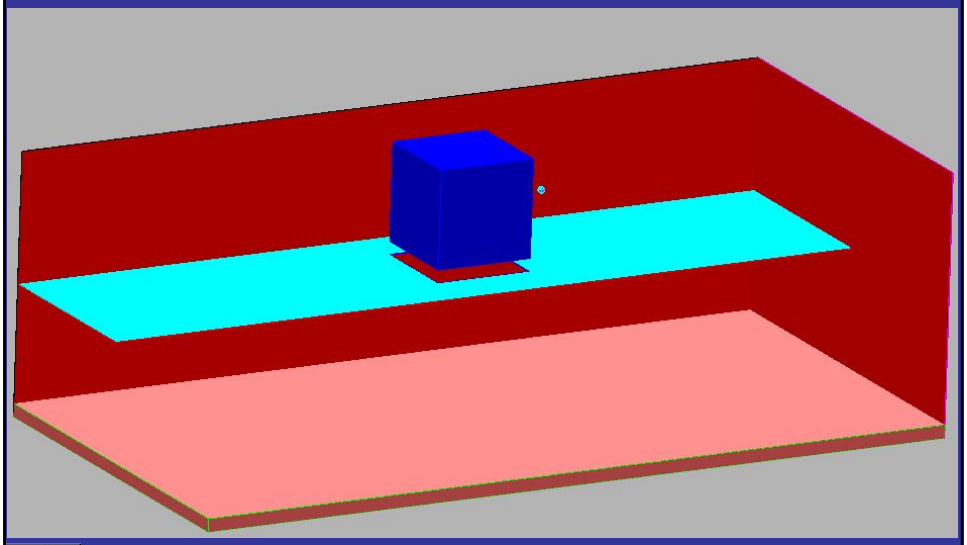
Geometry – figure from P3W

- Sources : 35 mm diameter cylindrical steel container 70 mm high
- AmO_2Be density "unknown" - range only specified by the manufacturer. 0.207 g cm^{-3} used in published calculations but 1.12 g cm^{-3} recommended in the problem specification.



- **Point of test** (reference position) 50 cm from graphite on the horizontal axis of symmetry of the assembly

Geometry (courtesy of P3-W)



Tasks

Determine at the point of test:

1. $d\Phi/dt$
2. Fluence: $\Phi(E)$ (energy bins provided)
3. $dH^*(10)/dt$
4. $dH_p(10, 0°)/dt$
5. $dH_p(10, 45°)/dt$
6. Component of Φ due to scatter.
7. Sensitivity of Φ to the ^{241}Am-Be and graphite density, and examine whether there are other major sources of uncertainty associated with Φ at the point of test.

Data provided

- ISO ^{241}Am-Be energy distribution
- Energy bins
- $H^*(10)/\Phi$ conversion coefficients
- $H_p(10, \theta)/\Phi$
- Neutron kerma factors
- Specifications of the ICRU phantoms (sphere and slab)
- Materials
- Geometry

Solutions

Letter	Code	Country
C	MCNP5	Poland
G	GEANT	Spain
O	TRIPOLI	France
T	MCBEND	UK
Q	MCNP5	US
W	MCNP5	US
Z	MCNPX	Spain

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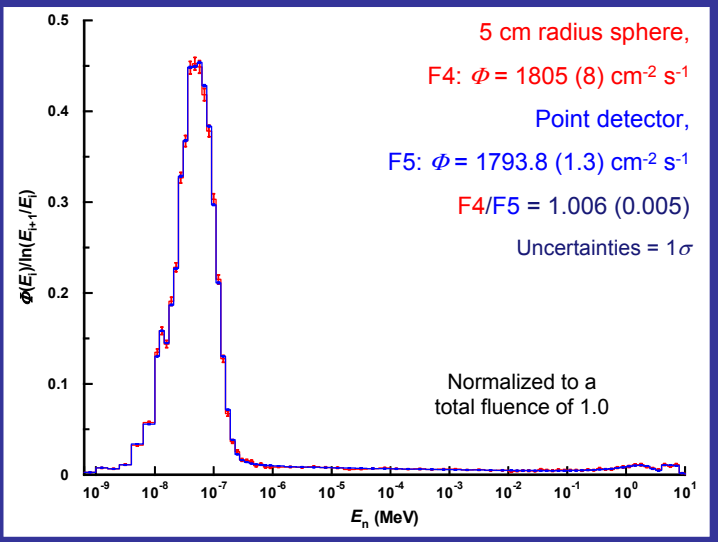
Tasks 1 & 2

Total fluence, Φ, and fluence-energy distribution, $\Phi(E)$ at the reference position

Reference solution: tallies



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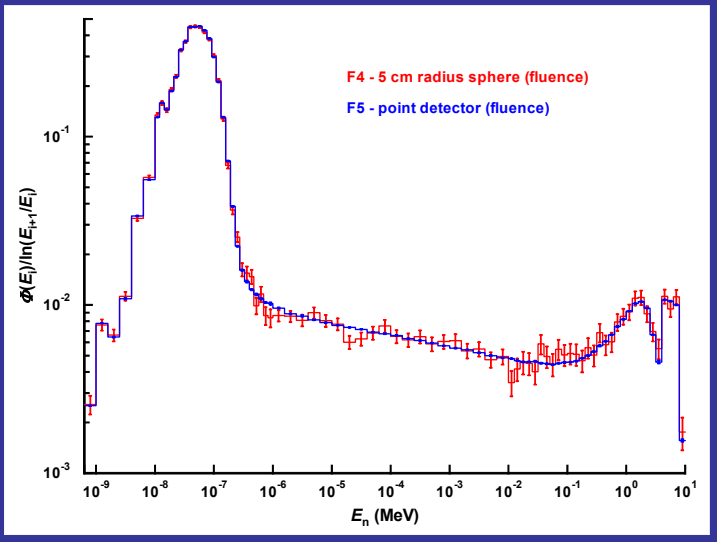
Reference solution: tallies



Tasks 1 & 2: contributed solutions

Total fluence, Φ, and fluence-energy distribution, $\Phi(E)$ at the reference position

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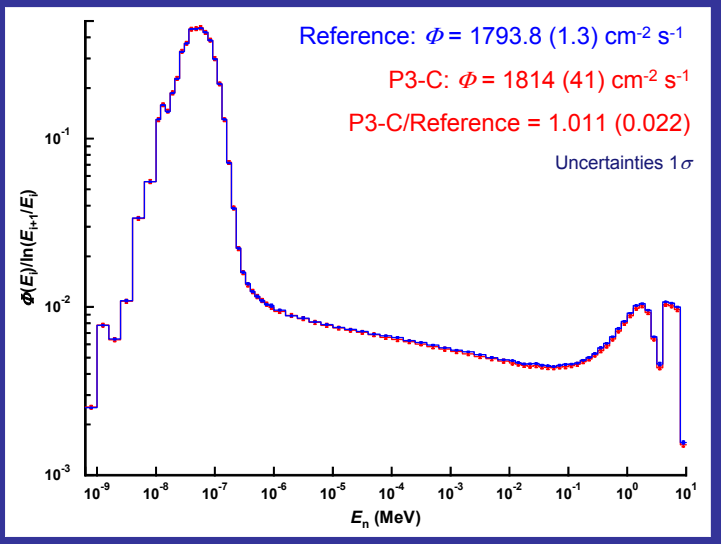
C - MCNP5, point detector



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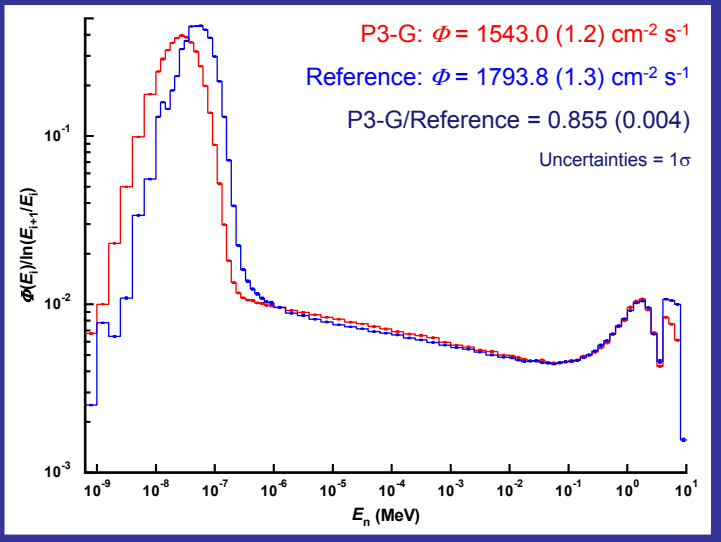
G – GEANT, point detector



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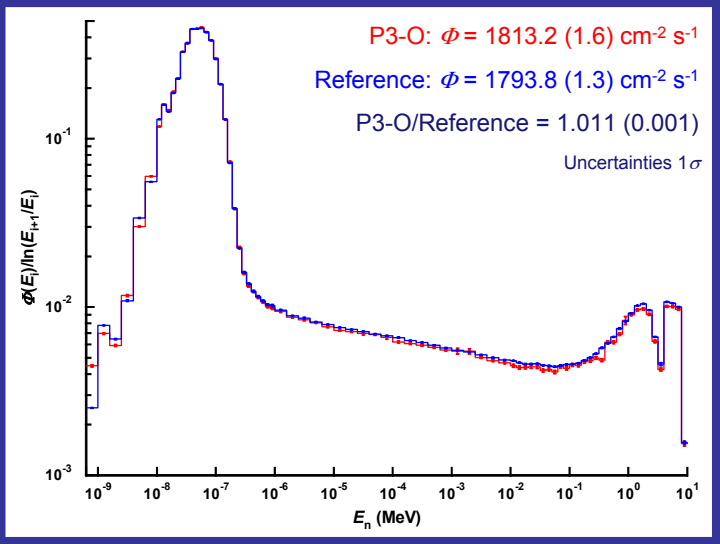
O – TRIPOLI, 15 cm radius sphere



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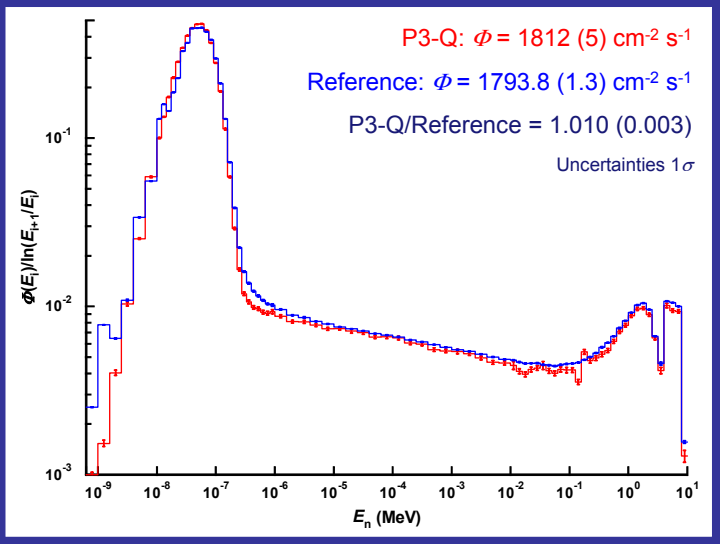
Q – MCNP5 , point detector



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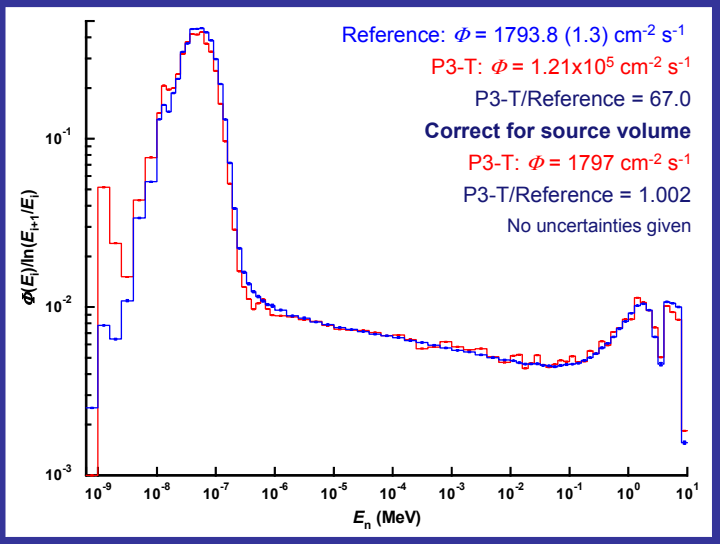
T – MCBEND , 15 cm radius sphere



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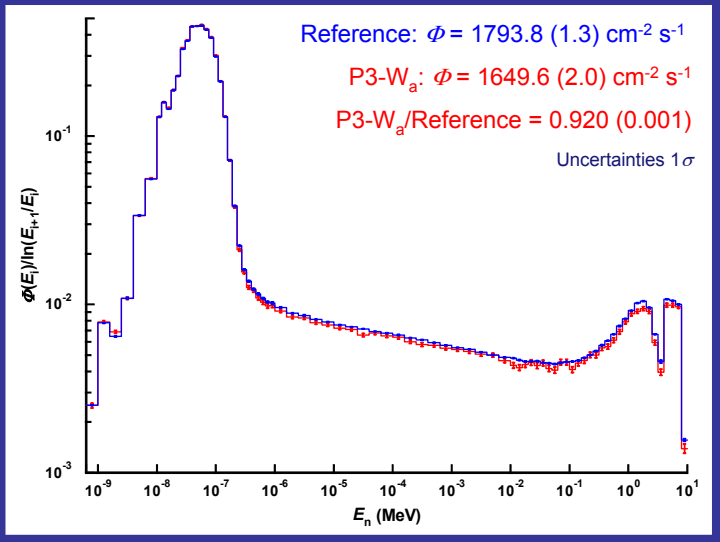
W_a - MCNP5, 15 cm radius sphere



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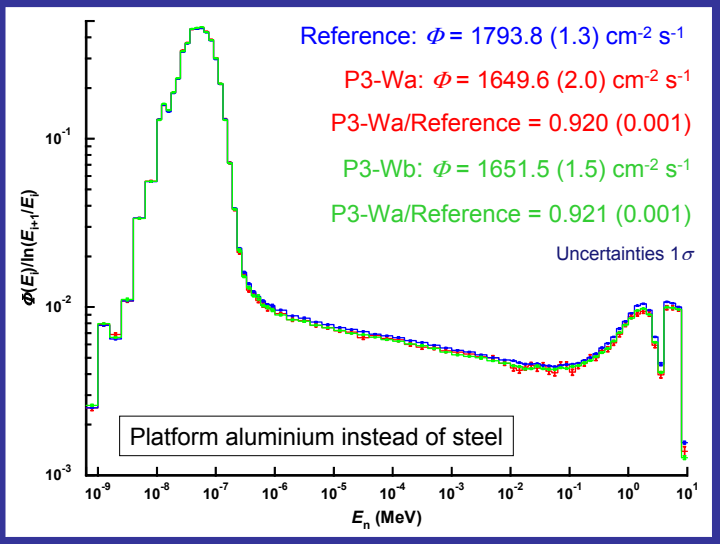
W_a = 15 cm sphere, W_b = point detector



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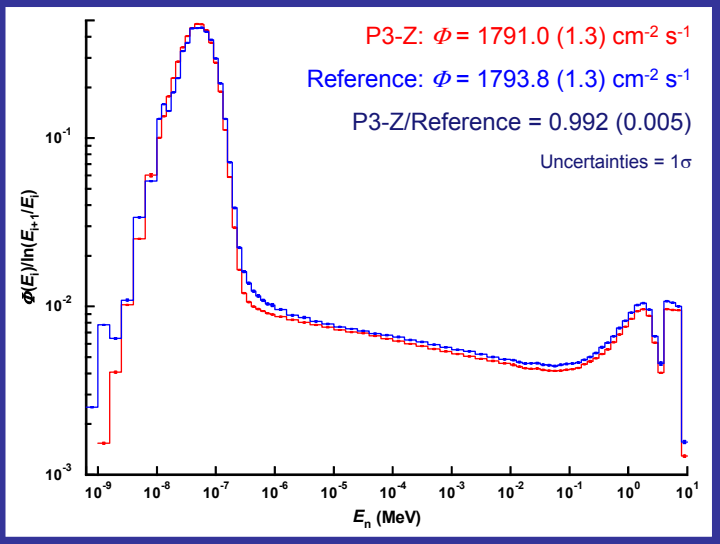
Z – MCNPX, point detector



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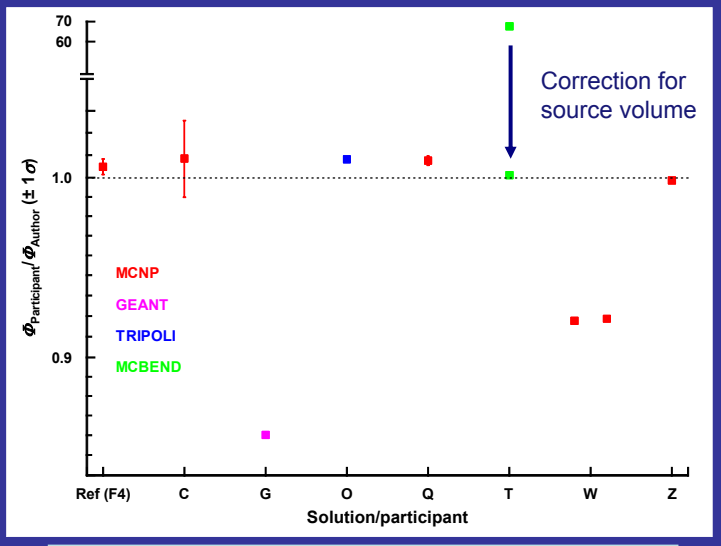
Task 1 summary



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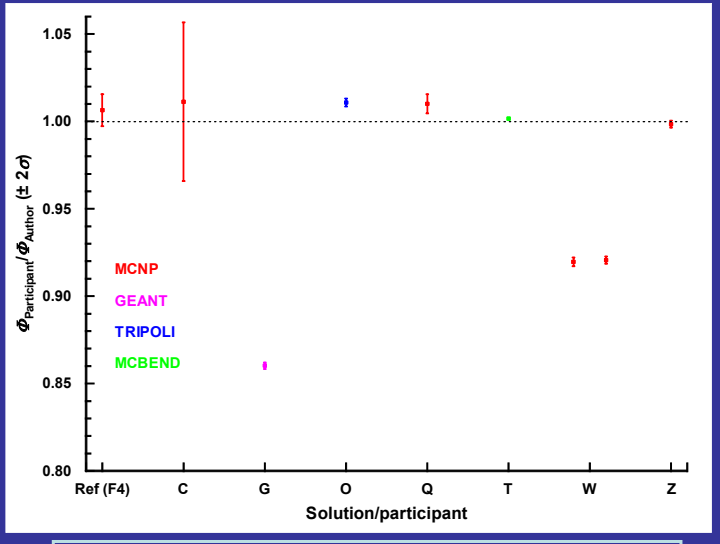
Task 1 summary



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Task 3

$H^*(10)$ rate

Task 2: Ambient dose equivalent, $H^*(10)$

Legitimate methods:

1. Take $\Phi(E)$ from Task 2 and fold with $H^*(10)/\Phi$ data from ICRU/ICRP
2. Use $H^*(10)/\Phi$ data from ICRU/ICRP within the MC program (in MCNP via the dose multiplier cards – DE and DF)
3. Take $\Phi(E)$ from Task 2, expand and align it, and then perform MC on the ICRU sphere
   - Calculate neutron AND photon fluences at 10 mm depth
   - Use kerma coefficients either in MC or outside the code
   - Add neutron and photon components
4. Calculate $H^*(10)$ from first principles via the secondary charged particle distribution linear energy transfer distribution and apply $Q(L)$

Incorrect methods:

1. Any method that places the ICRU sphere into the SIGMA geometry

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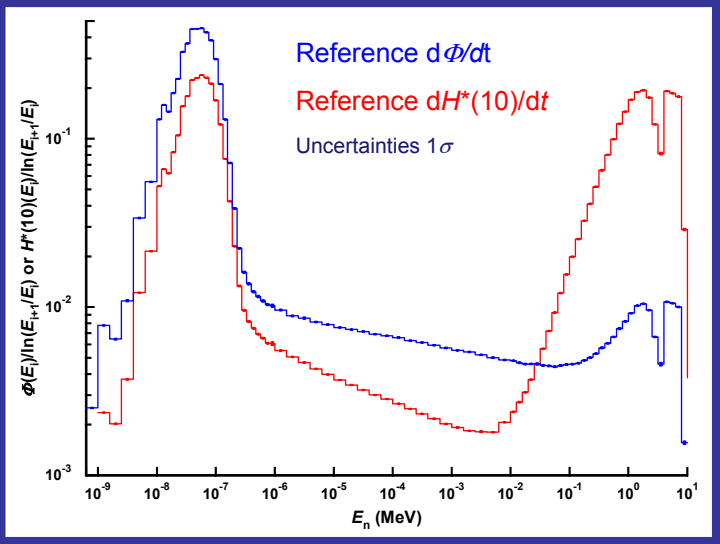
Reference solution: d*H**(10)/d*t*



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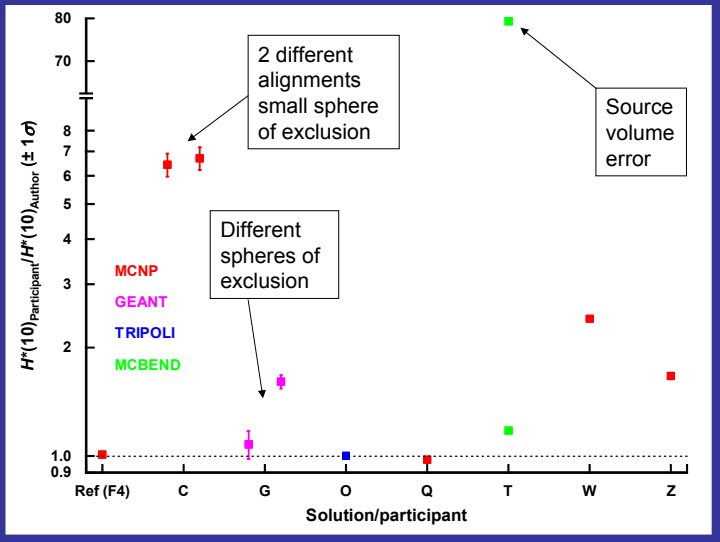
Task 3 – *H**(10) rate



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Ambient dose equivalent

- Easy calculation in MCNP – few participants simply applied the dose multipliers
- Some problems with understanding the quantity
- Some difficulties with spheres of exclusion: 1mm insufficient
- Generally small statistical uncertainties
- Some significant systematic uncertainties
- **Results poor compared to calculation of fluence**

Tasks 4 & 5

$H_p(10, 0^o)$ & $H_p(10, 45^o)$ rates

Task 3: Personal dose equivalent, $H_p(10, \theta)$

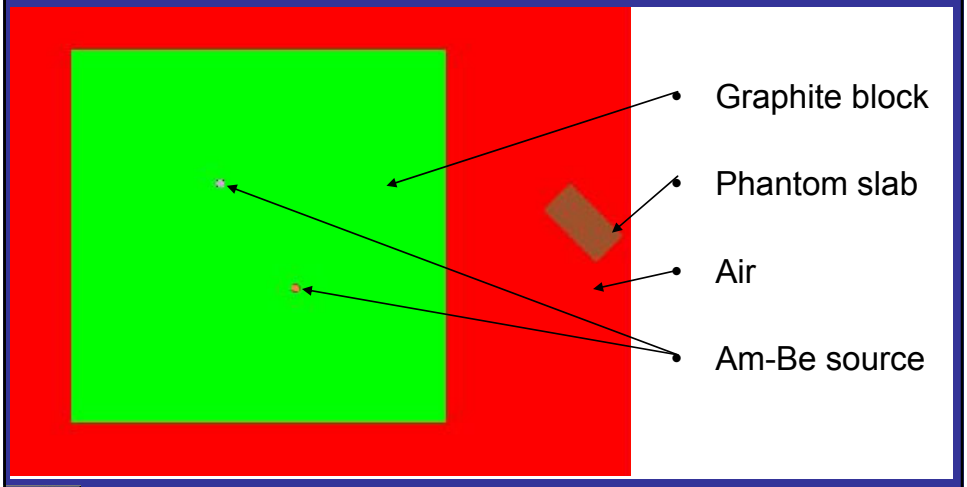
Options:

1. Calculate $\Phi(E, \theta)$ and fold with $H_p(10, \theta)/\Phi$ data from ICRU/ICRP
2. Calculate $\Phi(E, \theta)$ and apply $H_p(10, \theta)/\Phi$ data from ICRU/ICRP within the MC program
   - (in MCNP via the dose multiplier cards – DE and DF)
3. Calculate $\Phi(E, \theta)$ and use as the source for an $H_p(10)$ calculation in a phantom – DO NOT ALIGN FIELD
4. Put phantom into geometry and calculate $H_p(10)$ directly
   - Calculate neutron AND photon fluences at 10 mm depth
   - Use kerma coefficients either in MC or outside the code
   - Add neutron and photon components
5. Calculate $H_p(10)$ from first principles via the secondary charged particle distribution linear energy transfer distribution and apply $Q(L)$

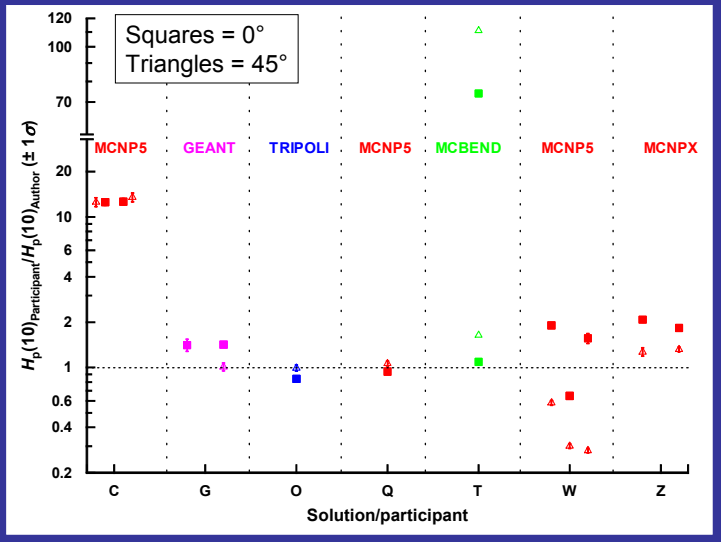
Personal dose equivalent

- **Field NOT aligned or expanded**
- Secondary photons generated within the phantom must be transported
- $H_p(10)$, unlike $H^*(10)$, is a "receptor present" quantity
- It is better calculated with the receptor (person/phantom) present in the geometry
- Scatter from the phantom to the graphite and back to the phantom is part of personal dose equivalent
- This is very different from $H^*(10)$ for which the receptor should never be placed in the geometry

Personal dose equivalent (courtesy of P3O)



$H_p(10)$ summary



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Personal dose equivalent

- Some participants aligned the field
- Some difficulties with spheres of exclusion: 1mm insufficient
- Some significant systematic uncertainties
- Difficulties with the concept of $H_p(10)$
- Few participants used the easiest and best method

Tasks 6 & 7

Perturbation of other parameters and scatter from floor and walls

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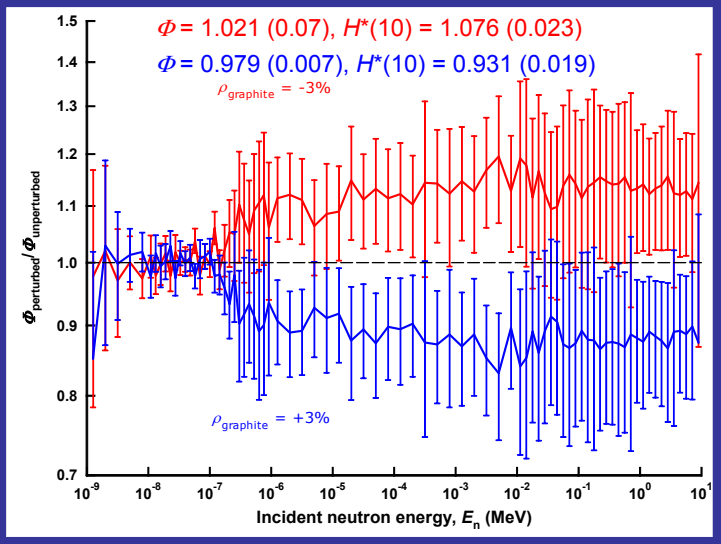
Scattered component of fluence

Solution	Fraction (%)	Comments
Tanner	**3.00 (0.10)**	**Cell flagging**
C – MCNP5	3.68 (0.08)	
G – GEANT	2.63 (0.37)	Voiding
O – TRIPOLI	4.22 (0.12)	Voiding
Q – MCNP5	2.11 (0.02)	
T – MCBEND	2.99	No uncertainty
W – MCNP5	5.69 (0.02)	Aluminium platform
Z - MCNPX	3.29 (0.10)	Voiding

Scatter

- All participants have attempted this part of the problem
- Some “voiding”
- Not sure how some participants tackled the problem
- Analysis complex – different methods applied and data in different formats
- General agreement between the solutions
- Full analysis in paper

MCNP5 – perturbation of graphite density

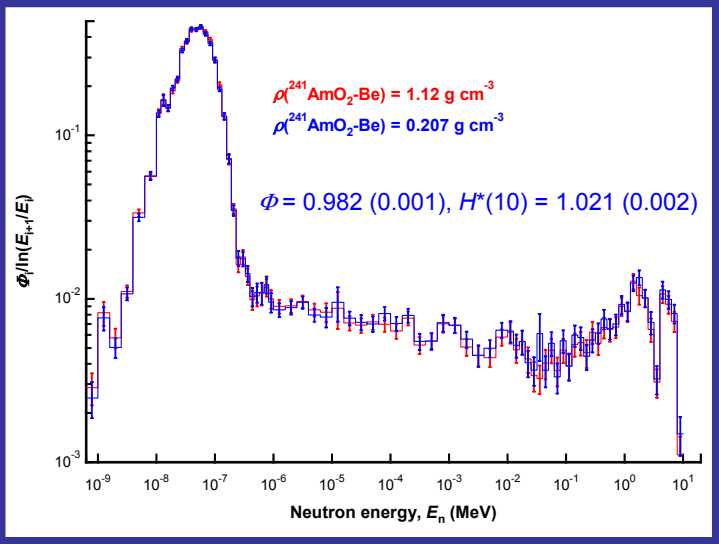


Density effects

Results from F2 and F1 tallies over the outer surface of the steel case and also from Table 130.

ρ (g cm^{-3})	n_{exit}/n_{source}	$(n, 2n)_{Am\text{-}Be}$	$(n, fiss)_{Am\text{-}Be}$	$(n, capt)_{Am\text{-}Be}$
0.207	1.0104	$2.27\ 10^{-2}$	$8.53\ 10^{-4}$	$-2.04\ 10^{-3}$
1.12	1.0597	$1.38\ 10^{-1}$	$4.71\ 10^{-3}$	$-1.12\ 10^{-2}$

Effect of changing source density



Material density

- All participants attempted
- Task rather vaguely defined
- Problems with comparison
- Full analysis in the paper for the proceedings

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Conclusions 1

- Significant number of solutions for a CPU intensive problem
- Generally the fluence calculations proved good
- Point detector is most efficient for the task – produces very small uncertainties in the total fluence
  - Not all participants considered carefully the sphere of exclusion
- Differences between the solutions generally large compared to the statistical uncertainties
- Only one participant did not quote statistical uncertainties

Conclusions 2

- Participants had significant difficulty in understanding the dose quantities – and how to calculate them
- Some large biases in the calculated results for dose equivalent
- Calculations of the scatter and density effects attempted by all participants
- Analysis of this part of the problem difficult
- Density effects produce large uncertainties compared to the uncertainties in the point detector results

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Acknowledgements

- CONRAD WP4 colleagues: Jean-Louis Chartier and Jean-Marc Bordy for the original work on SIGMA and discussions on the SIGMA field and ^{241}Am-Be sources
- Hamid Tagziria and others for discussions on the ^{241}Am-Be source construction and energy distribution
- All CONRAD WP4 colleagues who contributed usefully through discussions in our meetings
- THE PARTICIPANTS, without whom the exercise would have been pointless