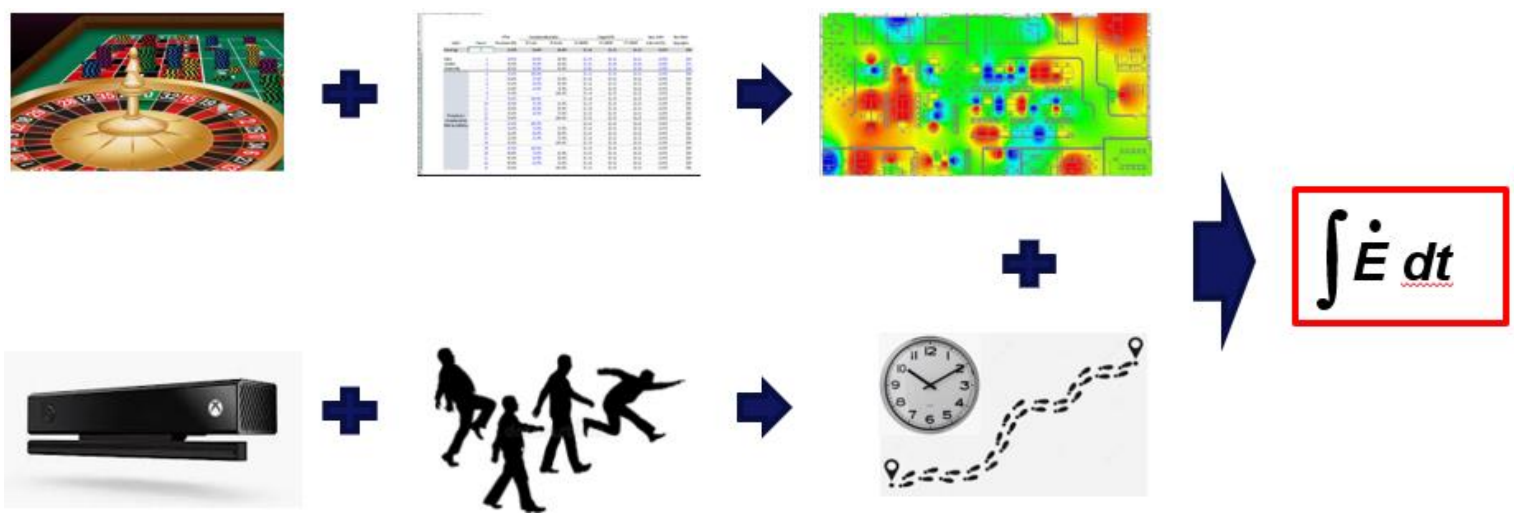
APPLICATION OF THE *PODIUM* APPROACH IN SIMULATED AND REALISTIC WORKPLACE NEUTRON FIELDS

J Eakins[1], M Abdelrahman[2], L Hager[1], E Kouroukla[1], J Jansen[1], P Lombardo[2], R Tanner[1], F Vanhavere[2] and O Van Hoey[2]

[1] United Kingdom Health Security Agency (UKHSA) RCE, Didcot, United Kingdom
[2] Belgian Nuclear Research Centre (SCK CEN), Mol, Belgium

PODIUM: Overall Approach

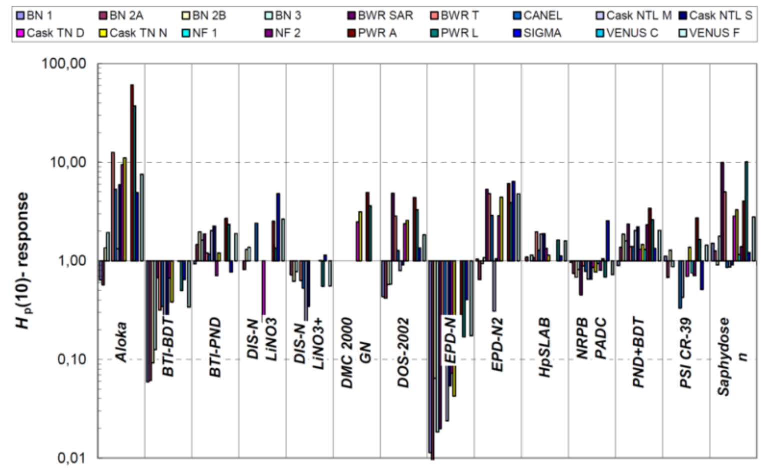
- Many problems associated with single point-of-test dosemeters…
  ⇒ **Could we use computational methods instead?**
- Similar approach for neutrons as photons
- Monte Carlo computer simulations to determine effective dose rates (and/or individual organs)
- Tracking cameras / software monitor motion of individuals in field
- Combining technologies provides **real-time assessments of doses !!**



PODIUM: Photons & Neutrons

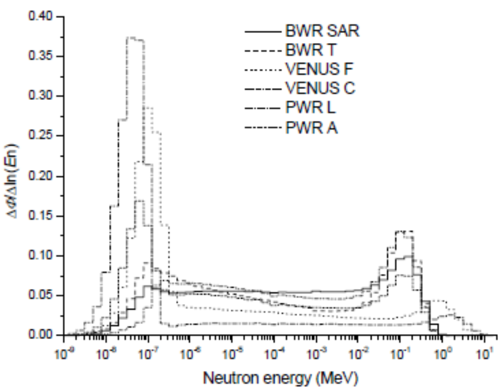
- Advantages in neutron workplaces similar to photons, or **even more so**…

  → Neutron dosemeters often perform worse !



- Many challenges also similar:
  - How best to map fields, track individuals and calculate real-time doses?

- But, significant differences too:
  - Radiation fields / shielding more homogenous
  - 'Micro-movements' / extremity doses less important
  - Mixed fields & very wide energy ranges
  - Radiation sources may be unknown (*e.g. fuel flasks*)
  - Much larger geometries (*e.g. reactor hall*)



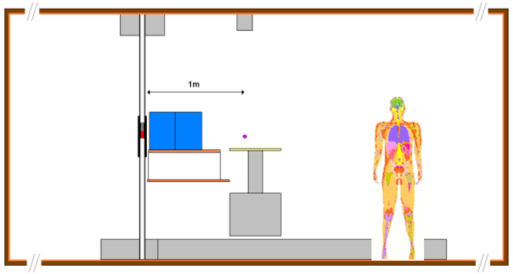
Neutron Dosimetry

QUESTION: How best to perform real-time dosimetry in mixed *n*/γ fields??

'Answer': Create realistic (time-dependent) Monte Carlo model of geometry and exposure scenario…

$\Rightarrow$ Calculate real-time doses to individuals moving within it

Perfect solution would be to model geometry with moveable voxel phantom [$E(\theta)$]:



- 'Correct' estimate of risk
- Correct field perturbation by phantom

- Difficult to implement / manipulate input file and initialize / run with current computational resources… $\rightarrow$ **real-time MC calculations very difficult !**
- Difficult to assign correct energy- and particle-dependent w_R to incident particles within calculation… $\rightarrow$ **only practical in monoenergetic fields !**

Neutron Dosimetry

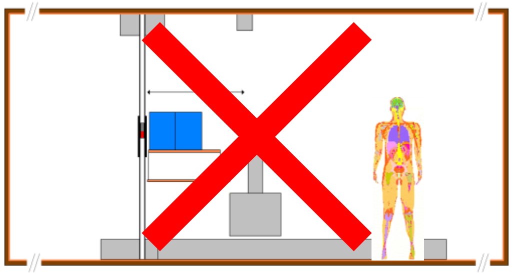
QUESTION: How best to perform real-time dosimetry in mixed *n*/γ fields??

'Answer': Create realistic (time-dependent) Monte Carlo model of geometry and exposure scenario…

⇒ Calculate real-time doses to individuals moving within it

Perfect solution would be to model geometry with moveable voxel phantom [$E(\theta)$]:

- 'Correct' estimate of risk
- Correct field perturbation by phantom



- Difficult to implement / manipulate input file and initialize / run with current computational resources… → **real-time MC calculations very difficult !**
- Difficult to assign correct energy- and particle-dependent w_R to incident particles within calculation… → **only practical in monoenergetic fields !**

Field Characterization

APPROACH: Use pre-calculated field maps

- **Map field discretely in location and angle**:

  1. Define a spatial grid (x, y) of points at facility
  2. Determine **fluence-energy distribution** of neutrons / photons at each point of grid, as **function of angle** (θ)
  3. Convolve with tabulated E/Φ data binned as function of energy + angle

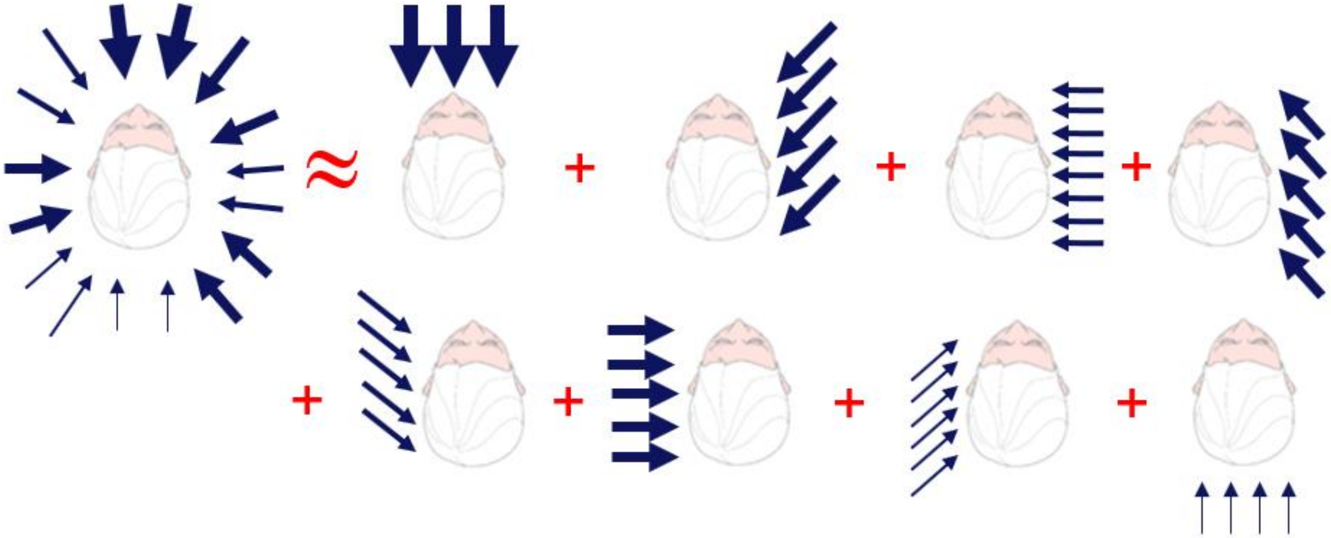
- Tracked individual 'snaps' to closest available point

… Take (x, y) coordinates and θ from tracking software as input

(Reasonable, as individuals are extended objects, so not located at single point anyhow)

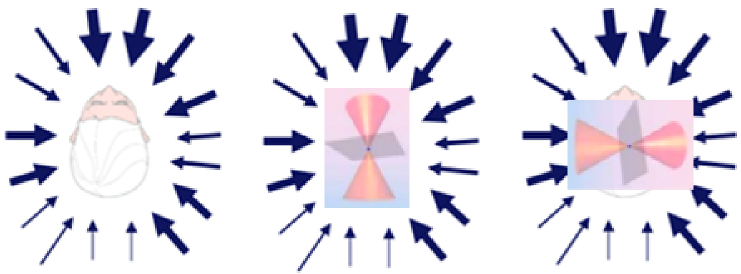
Field: Angle Decomposition

- Data in ICRP 116 for E/Φ only provided for standardized exposure conditions (e.g. plane-parallel, semi-ISO, ROT, etc.)… **but, real fields don't conform!**
- Approximate real field at each location as sum of plane-parallel components
- Deconvolve into 8 horizontal components as proof-of-concept…

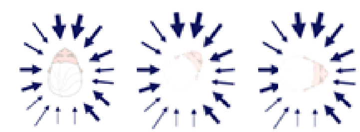


Field Characterization: Angles

Run MC to determine neutron energy distribution of field at each point of grid:



- Use oriented cones to bin angle components
- Convolve with appropriate *E/Φ* data
- Rotate cones by angles in horizontal plane
- → ***Results for individuals facing in different directions***

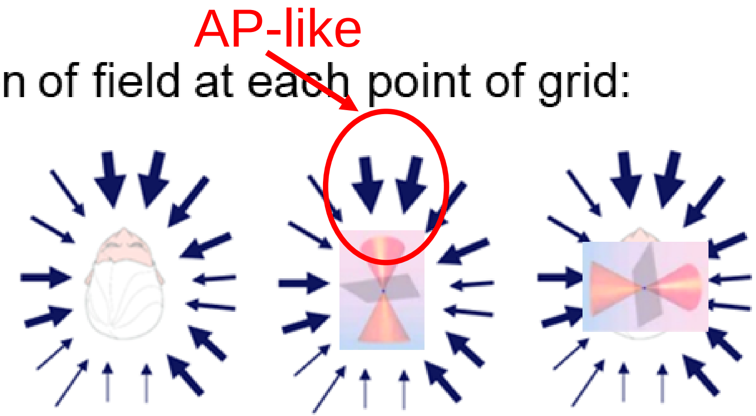


- For AP, PA, LLAT and RLAT, use *E*/Φ data in ICRP 116
- For 45°, 135°, 225° and 315°, generated new tables of *E*/Φ data (*monoenergetic, PP exposures of voxel phantoms*)

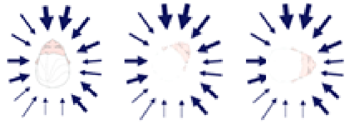
Neutron Energy (MeV)	*Effective dose per fluence (pSv cm²)*									
	0°	**45°**	**90°**	**135°**	**180°**	**225°**	**270°**	**315°**	**SS-I**	**IS-I**
1.00E-09	3.09	2.30	0.89	1.29	1.85	1.30	1.04	2.45	1.35	1.23
1.00E-08	3.55	2.71	0.98	1.53	2.11	1.54	1.15	2.91	1.58	1.54
2.50E-08	4.00	3.04	1.12	1.71	2.44	1.73	1.32	3.25	1.76	1.76
1.00E-07	5.20	3.97	1.42	2.25	3.25	2.28	1.70	4.26	2.33	2.19
2.00E-07	5.87	4.47	1.63	2.56	3.72	2.59	1.94	4.78	2.61	2.47
5.00E-07	6.59	5.11	1.86	2.97	4.33	3.00	2.21	5.48	2.99	2.85
1.00E-06	7.03	5.49	2.02	3.22	4.73	3.26	2.40	5.89	3.25	3.05
2.00E-06	7.39	5.77	2.11	3.42	5.02	3.46	2.52	6.18	3.37	3.27
5.00E-06	7.71	6.05	2.21	3.63	5.30	3.68	2.64	6.50	3.56	3.38
1.00E-05	7.82	6.14	2.24	3.72	5.44	3.76	2.65	6.59	3.62	3.42
2.00E-05	7.84	6.16	2.26	3.77	5.51	3.82	2.68	6.62	3.60	3.48
5.00E-05	7.82	6.17	2.24	3.82	5.55	3.86	2.66	6.61	3.65	3.45
1.00E-04	7.79	6.13	2.23	3.84	5.57	3.88	2.65	6.57	3.64	3.44
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Field Characterization: Angles

Run MC to determine neutron energy distribution of field at each point of grid:



- Use oriented cones to bin angle components
- Convolve with appropriate *E/Φ* data
- Rotate cones by angles in horizontal plane
- → ***Results for individuals facing in different directions***

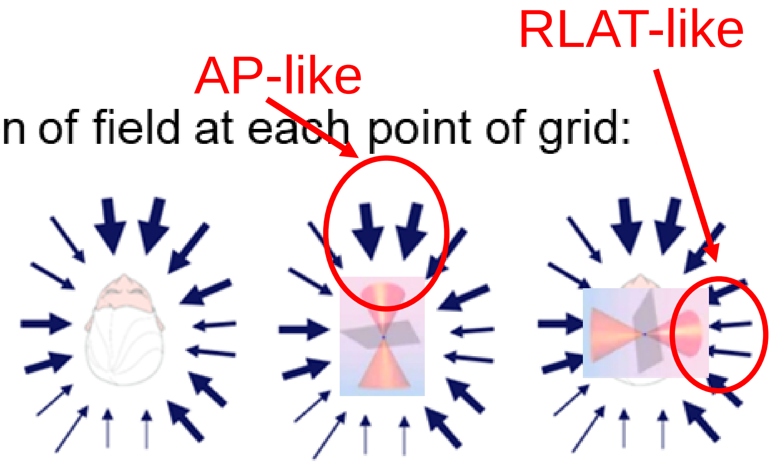


- For AP, PA, LLAT and RLAT, use *E*/Φ data in ICRP 116
- For 45°, 135°, 225° and 315°, generated new tables of *E*/Φ data (*monoenergetic, PP exposures of voxel phantoms*)

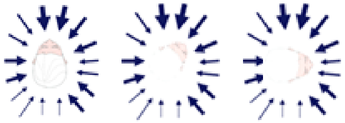
Neutron Energy (MeV)	*Effective dose per fluence (pSv cm²)*									
	0°	45°	90°	135°	180°	225°	270°	315°	SS-I	IS-I
1.00E-09	3.09	2.30	0.89	1.29	1.85	1.30	1.04	2.45	1.35	1.23
1.00E-08	3.55	2.71	0.98	1.53	2.11	1.54	1.15	2.91	1.58	1.54
2.50E-08	4.00	3.04	1.12	1.71	2.44	1.73	1.32	3.25	1.76	1.76
1.00E-07	5.20	3.97	1.42	2.25	3.25	2.28	1.70	4.26	2.33	2.19
2.00E-07	5.87	4.47	1.63	2.56	3.72	2.59	1.94	4.78	2.61	2.47
5.00E-07	6.59	5.11	1.86	2.97	4.33	3.00	2.21	5.48	2.99	2.85
1.00E-06	7.03	5.49	2.02	3.22	4.73	3.26	2.40	5.89	3.25	3.05
2.00E-06	7.39	5.77	2.11	3.42	5.02	3.46	2.52	6.18	3.37	3.27
5.00E-06	7.71	6.05	2.21	3.63	5.30	3.68	2.64	6.50	3.56	3.38
1.00E-05	7.82	6.14	2.24	3.72	5.44	3.76	2.65	6.59	3.62	3.42
2.00E-05	7.84	6.16	2.26	3.77	5.51	3.82	2.68	6.62	3.60	3.48
5.00E-05	7.82	6.17	2.24	3.82	5.55	3.86	2.66	6.61	3.65	3.45
1.00E-04	7.79	6.13	2.23	3.84	5.57	3.88	2.65	6.57	3.64	3.44
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Field Characterization: Angles

Run MC to determine neutron energy distribution of field at each point of grid:



- Use oriented cones to bin angle components
- Convolve with appropriate *E/Φ* data
- Rotate cones by angles in horizontal plane
- → ***Results for individuals facing in different directions***

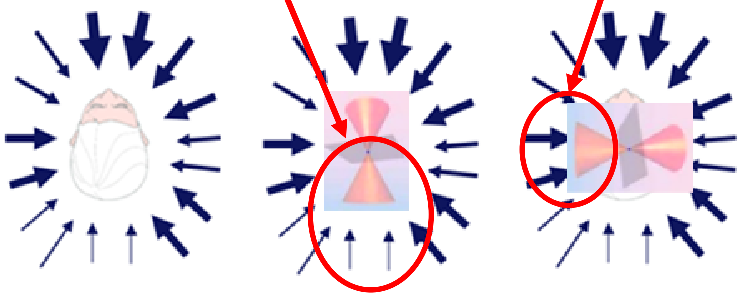


- For AP, PA, LLAT and RLAT, use *E*/Φ data in ICRP 116
- For 45°, 135°, 225° and 315°, generated new tables of *E*/Φ data (*monoenergetic, PP exposures of voxel phantoms*)

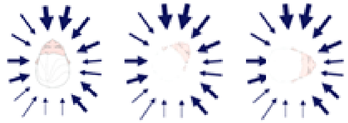
Neutron Energy (MeV)	*Effective dose per fluence (pSv cm²)*									
	0°	**45°**	**90°**	**135°**	**180°**	**225°**	**270°**	**315°**	**SS-I**	**IS-I**
1.00E-09	3.09	2.30	0.89	1.29	1.85	1.30	1.04	2.45	1.35	1.23
1.00E-08	3.55	2.71	0.98	1.53	2.11	1.54	1.15	2.91	1.58	1.54
2.50E-08	4.00	3.04	1.12	1.71	2.44	1.73	1.32	3.25	1.76	1.76
1.00E-07	5.20	3.97	1.42	2.25	3.25	2.28	1.70	4.26	2.33	2.19
2.00E-07	5.87	4.47	1.63	2.56	3.72	2.59	1.94	4.78	2.61	2.47
5.00E-07	6.59	5.11	1.86	2.97	4.33	3.00	2.21	5.48	2.99	2.85
1.00E-06	7.03	5.49	2.02	3.22	4.73	3.26	2.40	5.89	3.25	3.05
2.00E-06	7.39	5.77	2.11	3.42	5.02	3.46	2.52	6.18	3.37	3.27
5.00E-06	7.71	6.05	2.21	3.63	5.30	3.68	2.64	6.50	3.56	3.38
1.00E-05	7.82	6.14	2.24	3.72	5.44	3.76	2.65	6.59	3.62	3.42
2.00E-05	7.84	6.16	2.26	3.77	5.51	3.82	2.68	6.62	3.60	3.48
5.00E-05	7.82	6.17	2.24	3.82	5.55	3.86	2.66	6.61	3.65	3.45
1.00E-04	7.79	6.13	2.23	3.84	5.57	3.88	2.65	6.57	3.64	3.44
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Field Characterization: Angles

Run MC to determine neutron energy distribution of field at each point of grid:



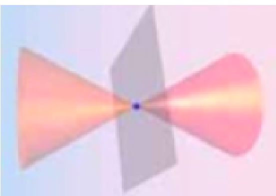
- Use oriented cones to bin angle components
- Convolve with appropriate *E/Φ* data
- Rotate cones by angles in horizontal plane
- → ***Results for individuals facing in different directions***



- For AP, PA, LLAT and RLAT, use *E*/Φ data in ICRP 116
- For 45°, 135°, 225° and 315°, generated new tables of *E*/Φ data (*monoenergetic, PP exposures of voxel phantoms*)

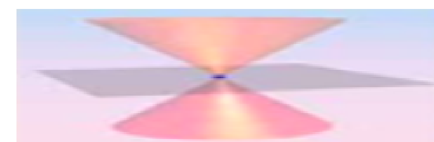
Neutron Energy (MeV)	*Effective dose per fluence (pSv cm²)*									
	0°	**45°**	**90°**	**135°**	**180°**	**225°**	**270°**	**315°**	**SS-I**	**IS-I**
1.00E-09	3.09	2.30	0.89	1.29	1.85	1.30	1.04	2.45	1.35	1.23
1.00E-08	3.55	2.71	0.98	1.53	2.11	1.54	1.15	2.91	1.58	1.54
2.50E-08	4.00	3.04	1.12	1.71	2.44	1.73	1.32	3.25	1.76	1.76
1.00E-07	5.20	3.97	1.42	2.25	3.25	2.28	1.70	4.26	2.33	2.19
2.00E-07	5.87	4.47	1.63	2.56	3.72	2.59	1.94	4.78	2.61	2.47
5.00E-07	6.59	5.11	1.86	2.97	4.33	3.00	2.21	5.48	2.99	2.85
1.00E-06	7.03	5.49	2.02	3.22	4.73	3.26	2.40	5.89	3.25	3.05
2.00E-06	7.39	5.77	2.11	3.42	5.02	3.46	2.52	6.18	3.37	3.27
5.00E-06	7.71	6.05	2.21	3.63	5.30	3.68	2.64	6.50	3.56	3.38
1.00E-05	7.82	6.14	2.24	3.72	5.44	3.76	2.65	6.59	3.62	3.42
2.00E-05	7.84	6.16	2.26	3.77	5.51	3.82	2.68	6.62	3.60	3.48
5.00E-05	7.82	6.17	2.24	3.82	5.55	3.86	2.66	6.61	3.65	3.45
1.00E-04	7.79	6.13	2.23	3.84	5.57	3.88	2.65	6.57	3.64	3.44
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Field Characterization: Angles

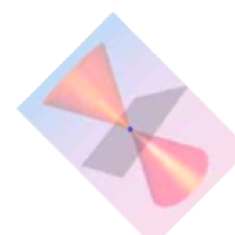


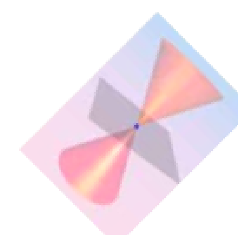
- For AP, PA, LLAT and RLAT, use E/Φ data in ICRP 116
- For 45°, 135°, 225° and 315°, generated new tables of E/Φ data (*monoenergetic, PP exposures of voxel phantoms*)

What about other, non-horizontal planes?



- Can use SS-ISO and IS-ISO in more isotropic fields (i.e. mainly horizontal exposures)
- Vertical characterization sometimes needed?
  $\rightarrow$ More E/Φ data





- **Important thing is full 4π accounted for…**

Field Characterization: Summary

1. Use MC to calculate:
   - Fluence in cone angles of 45°, for each 45° in horizontal plane
   - Fluence components in non-horizontal cones
2. Convolve using tally multipliers within MCNP to give various angular components of effective dose
3. Normalize result in each cone to account for full 4π fluence-field
4. Scale results by source activity, and sum to give *E* rates…

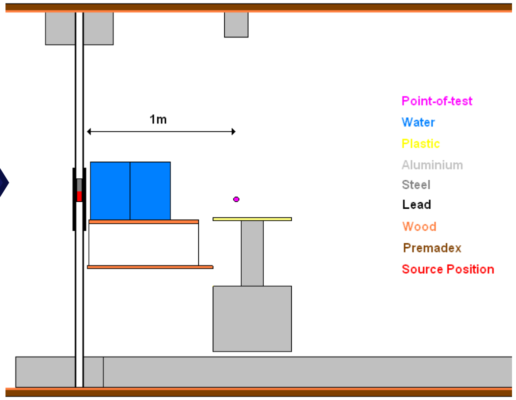
If characterizing fluence-energy, can also calculate $H^*(10)$ map:

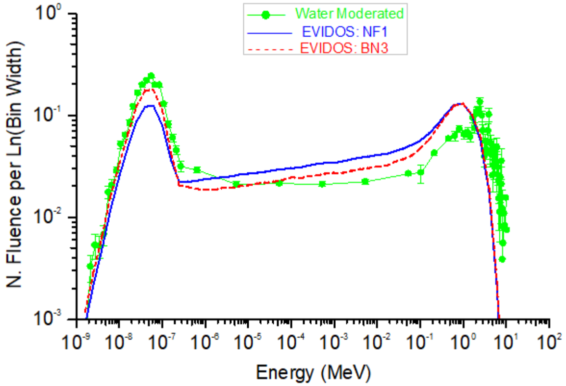
- Useful as a check
- Useful for confirmatory measurements with survey instruments
- Useful to provide scaling factor
- Useful as an alarm in time-dependent fields (e.g. with installed monitor)

Ex1: A Simple "Workplace" Field

Aim: Generate a field with energy distribution resembling a workplace field using ^{241}Am-Be neutron source available at UKHSA

⇒ Introduce water tanks close to source to moderate fast ^{241}Am-Be neutrons



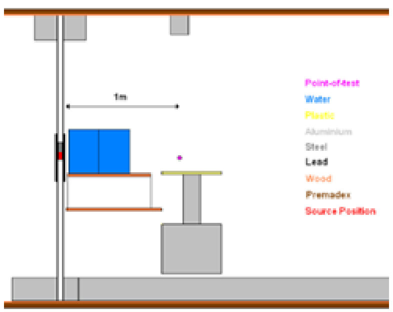


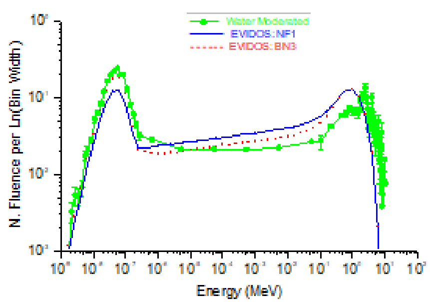
- Field is strongly angle- and location-dependent (*…as desired* ☺)
- Dose to 'person' in field as function of position and orientation can be determined…

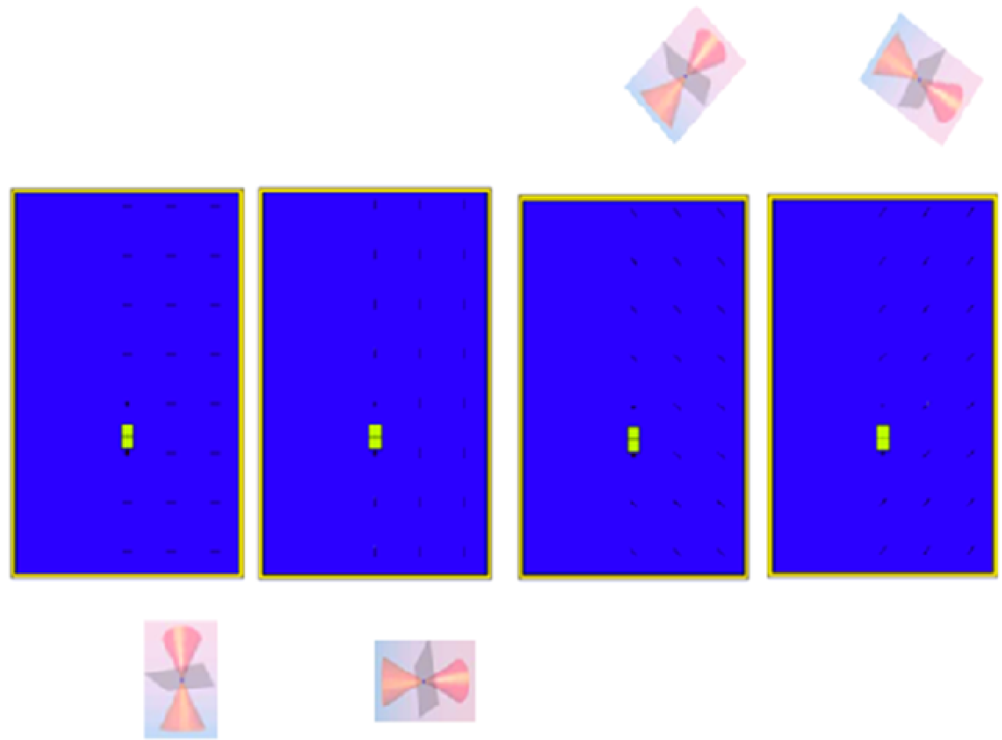
…and compared against subsequent measurements

UKHSA field: Dose Mapping

- MCNP input file of water-moderated UKHSA Am-Be facility
- Choose (x, y) grid of 1 m × 1 m initially → Can refine / interpolate if too coarse
- Characterize fluence-energy-angle distribution on grid in eight 45° cones + 135° SS-ISO cone + 135° IS-ISO cone

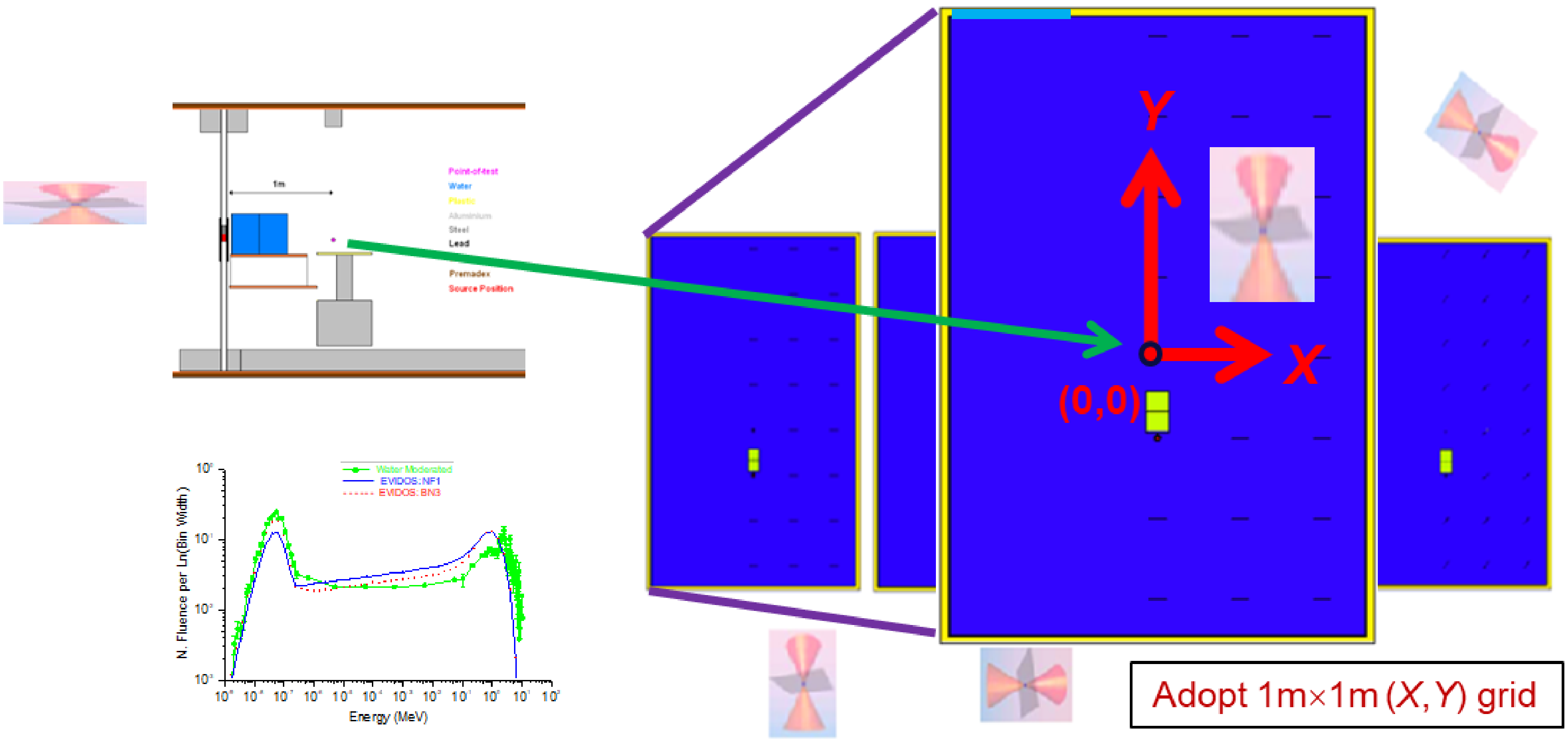




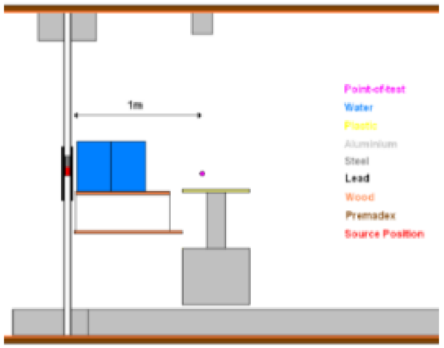


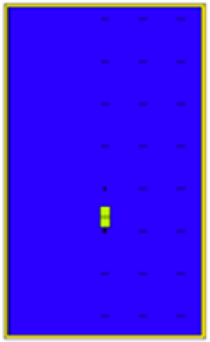
UKHSA field: Dose Mapping

- MCNP input file of water-moderated UKHSA Am-Be facility
- Choose (x, y) grid of 1 m × 1 m initially → Can refine / interpolate if too coarse
- Characterize fluence-energy-angle distribution on grid in eight 45° cones + 135° SS-ISO cone + 135° IS-ISO cone



Effective Dose





0° — Effective Dose Rate: DOOR

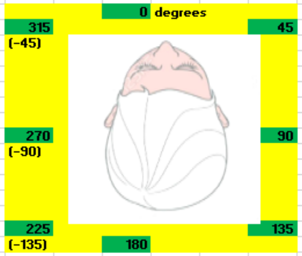
(0,Y) µSv/h	1sd	(100,Y) µSv/h	1sd	(200,Y) µSv/h	1sd	
0.58	0.01	0.63	0.01	0.68	0.01	(X,400)
0.73	0.01	0.84	0.01	1.02	0.01	(X,300)
1.09	0.01	1.44	0.02	1.95	0.02	(X,200)
1.87	0.02	3.22	0.03	4.75	0.03	(X,100)
4.05	0.03	16.09	0.06	18.07	0.06	(X,0)
SOURCE		90.50	0.13	25.15	0.07	(X,-100)
169.95	0.25	79.09	0.16	34.15	0.11	(X,-200)
45.82	0.13	34.05	0.11	22.17	0.08	(X,-300)

315° — Effective Dose Rate: DOOR

(0,Y) µSv/h	1sd	(100,Y) µSv/h	1sd	(200,Y) µSv/h	1sd	
0.52	0.01	0.54	0.01	0.59	0.01	(X,400)
0.67	0.01	0.74	0.01	0.98	0.02	(X,300)
1.04	0.01	1.30	0.02	1.92	0.02	(X,200)
1.84	0.02	3.22	0.03	4.74	0.04	(X,100)
4.09	0.03	16.05	0.07	18.18	0.08	(X,0)
SOURCE		158.72	0.23	42.28	0.12	(X,-100)
150.62	0.22	86.71	0.18	37.30	0.11	(X,-200)
41.02	0.11	37.03	0.12	24.12	0.09	(X,-300)

45° — Effective Dose Rate: DOOR

(0,Y) µSv/h	1sd	(100,Y) µSv/h	1sd	(200,Y) µSv/h	1sd	
0.51	0.01	0.55	0.01	0.61	0.01	(X,400)
0.65	0.01	0.74	0.01	1.13	0.02	(X,300)
1.01	0.01	1.29	0.02	2.29	0.03	(X,200)
1.81	0.02	3.66	0.03	5.74	0.04	(X,100)
4.04	0.03	19.96	0.08	22.79	0.09	(X,0)
SOURCE		91.05	0.15	25.39	0.08	(X,-100)
154.92	0.23	46.08	0.11	20.80	0.07	(X,-200)
42.12	0.12	20.90	0.07	13.77	0.06	(X,-300)



270° — Effective Dose Rate: DOOR

(0,Y) µSv/h	1sd	(100,Y) µSv/h	1sd	(200,Y) µSv/h	1sd	
0.56	0.01	0.61	0.01	1.59	0.03	(X,400)
0.73	0.01	0.83	0.01	1.40	0.02	(X,300)
1.13	0.02	1.44	0.02	2.91	0.03	(X,200)
1.96	0.02	4.48	0.04	7.34	0.05	(X,100)
4.32	0.03	25.86	0.09	30.20	0.10	(X,0)
SOURCE		174.54	0.26	46.39	0.13	(X,-100)
79.13	0.12	77.01	0.18	33.50	0.12	(X,-200)
23.06	0.07	33.15	0.12	21.68	0.09	(X,-300)

90° — Effective Dose Rate: DOOR

(0,Y) µSv/h	1sd	(100,Y) µSv/h	1sd	(200,Y) µSv/h	1sd	
0.52	0.01	0.52	0.01	0.55	0.01	(X,400)
0.68	0.01	0.72	0.01	0.94	0.01	(X,300)
1.07	0.01	1.28	0.02	1.89	0.02	(X,200)
1.91	0.02	3.25	0.03	4.74	0.03	(X,100)
4.23	0.03	15.96	0.06	17.96	0.06	(X,0)
SOURCE		117.39	0.17	32.17	0.09	(X,-100)
88.82	0.13	46.43	0.11	21.01	0.08	(X,-200)
25.50	0.07	20.93	0.07	13.86	0.06	(X,-300)

225° — Effective Dose Rate: DOOR

(0,Y) µSv/h	1sd	(100,Y) µSv/h	1sd	(200,Y) µSv/h	1sd	
0.79	0.01	0.88	0.02	0.98	0.02	(X,400)
1.01	0.02	1.20	0.02	1.69	0.02	(X,300)
1.48	0.02	1.99	0.02	3.28	0.04	(X,200)
2.33	0.02	5.06	0.04	8.05	0.06	(X,100)
4.70	0.03	28.11	0.11	32.94	0.12	(X,0)
SOURCE		154.40	0.26	41.35	0.13	(X,-100)
86.84	0.13	41.41	0.10	18.94	0.07	(X,-200)
25.07	0.07	19.02	0.07	12.63	0.05	(X,-300)

180° — Effective Dose Rate: DOOR

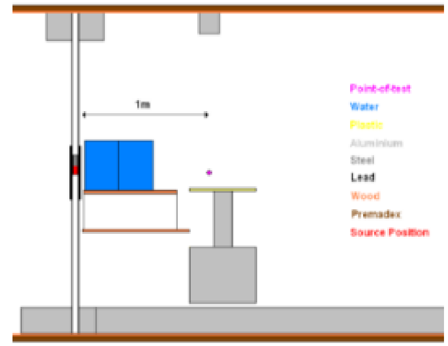
(0,Y) µSv/h	1sd	(100,Y) µSv/h	1sd	(200,Y) µSv/h	1sd	
0.88	0.02	0.95	0.02	1.01	0.02	(X,400)
1.14	0.02	1.29	0.02	1.59	0.02	(X,300)
1.63	0.02	2.15	0.03	3.04	0.03	(X,200)
2.48	0.03	4.82	0.04	7.38	0.05	(X,100)
4.84	0.03	25.41	0.09	29.28	0.10	(X,0)
SOURCE		80.72	0.12	22.84	0.07	(X,-100)
89.47	0.14	20.90	0.06	20.35	0.06	(X,-200)
32.09	0.09	20.48	0.06	13.50	0.05	(X,-300)

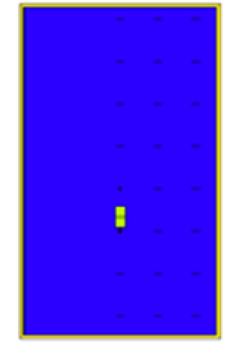
135° — Effective Dose Rate: DOOR

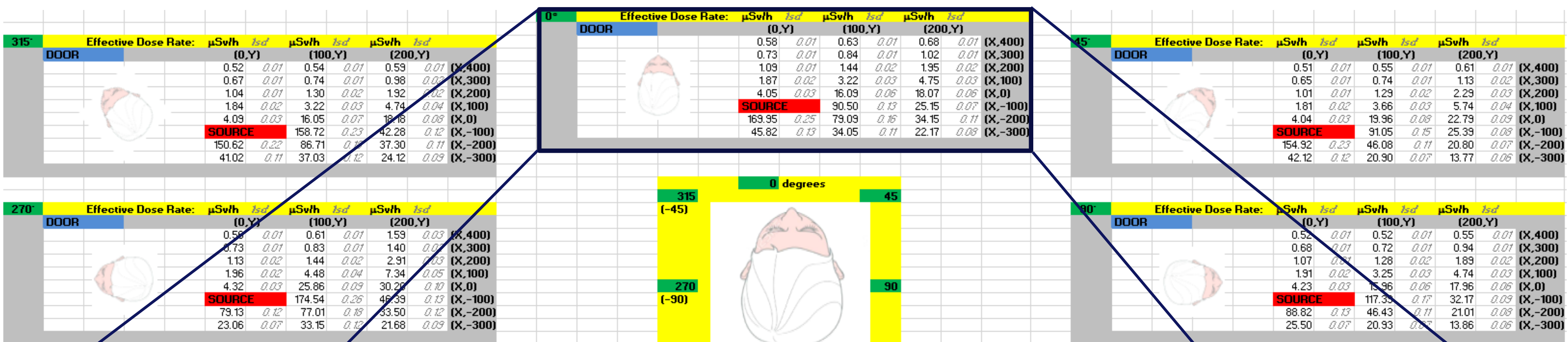
(0,Y) µSv/h	1sd	(100,Y) µSv/h	1sd	(200,Y) µSv/h	1sd	
0.76	0.01	0.78	0.01	0.82	0.01	(X,400)
0.99	0.02	1.09	0.02	1.08	0.02	(X,300)
1.44	0.02	1.83	0.02	1.94	0.02	(X,200)
2.30	0.02	3.42	0.03	4.57	0.03	(X,100)
4.64	0.03	14.88	0.06	16.49	0.07	(X,0)
SOURCE		88.53	0.13	24.81	0.07	(X,-100)
89.47	0.14	59.17	0.12	26.05	0.08	(X,-200)
25.70	0.07	25.96	0.08	17.03	0.07	(X,-300)

(Only neutron component included here)

Effective Dose

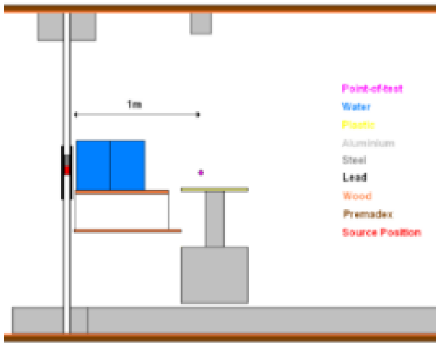


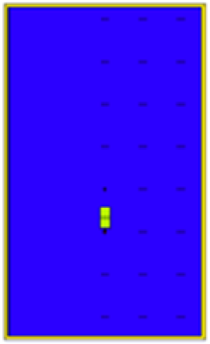




0°	Effective Dose Rate:	µSv/h	1sd	µSv/h	1sd	µSv/h	1sd	
DOOR		(0,Y)		(100,Y)		(200,Y)		
		0.58	0.01	0.63	0.01	0.68	0.01	(X,400)
		0.73	0.01	0.84	0.01	1.02	0.01	(X,300)
		1.09	0.01	1.44	0.02	1.95	0.02	(X,200)
		1.87	0.02	3.22	0.03	4.75	0.03	(X,100)
		4.05	0.03	16.09	0.06	18.07	0.06	(X,0)
		SOURCE		90.50	0.13	25.15	0.07	(X,-100)
		169.95	0.25	79.09	0.16	34.15	0.11	(X,-200)
		45.82	0.13	34.05	0.11	22.17	0.08	(X,-300)

… and also *H*(10)*



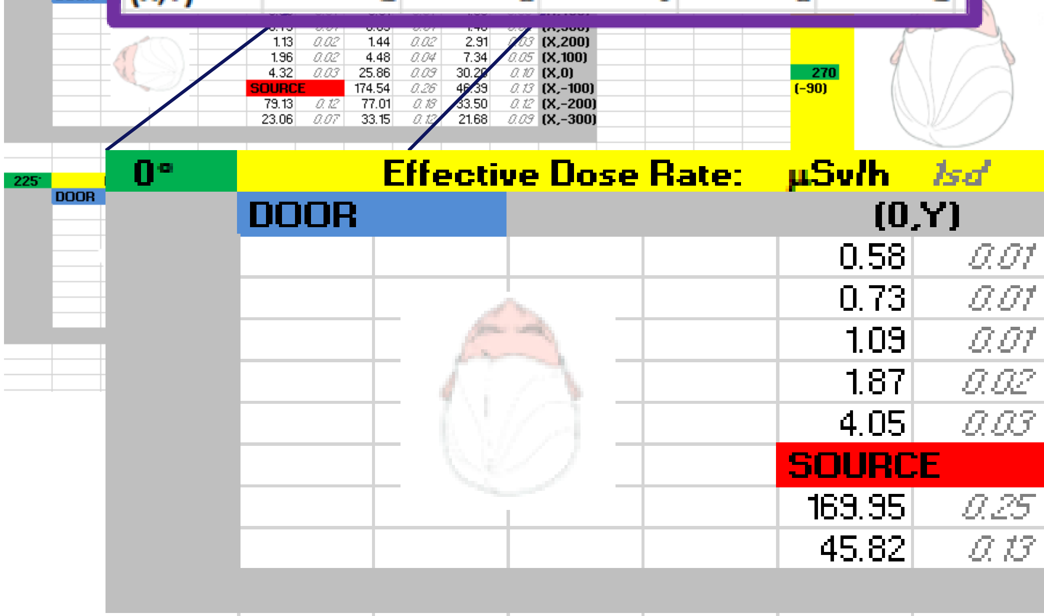


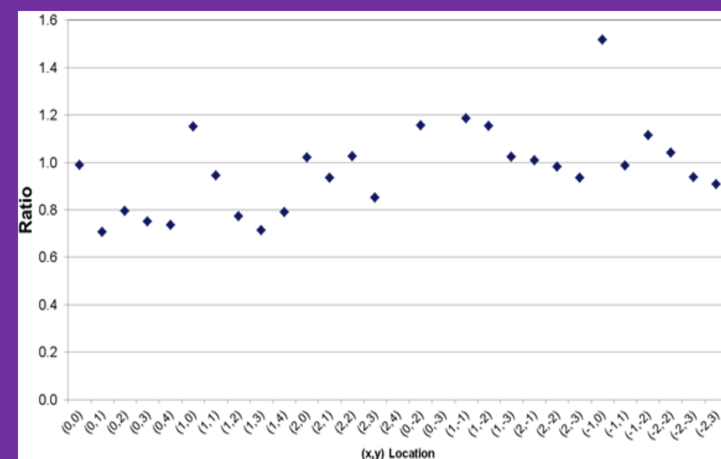
	H*(10) Rate (uSv/hr)				
4			1.4	1.5	1.6
3			1.8	2.0	2.3
2			2.7	3.4	4.1
1			4.8	7.0	8.6
0			10.0	26.7	30.4
-1			SOURCE	144.8	42.2
-2			141.3	75.4	35.5
-3			43.0	35.9	24.1
(X,Y)	-2	-1	0	1	2

0°	Effective Dose Rate:	µSv/h	1sd	µSv/h	1sd	µSv/h	1sd	
DOOR		(0,Y)		(100,Y)		(200,Y)		
		0.58	0.01	0.63	0.01	0.68	0.01	(X,400)
		0.73	0.01	0.84	0.01	1.02	0.01	(X,300)
		1.09	0.01	1.44	0.02	1.95	0.02	(X,200)
		1.87	0.02	3.22	0.03	4.75	0.03	(X,100)
		4.05	0.03	16.09	0.06	18.07	0.06	(X,0)
		SOURCE		90.50	0.13	25.15	0.07	(X,-100)
		169.95	0.25	79.09	0.16	34.15	0.11	(X,-200)
		45.82	0.13	34.05	0.11	22.17	0.08	(X,-300)

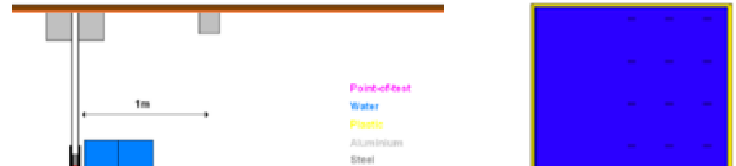
… and also *H**(10)

	H*(10) Rate (uSv/hr)				
4			1.4	1.5	1.6
3			1.8	2.0	2.3
2			2.7	3.4	4.1
1			4.8	7.0	8.6
0			10.0	26.7	30.4
-1			SOURCE	144.8	42.2
-2			141.3	75.4	35.5
-3			43.0	35.9	24.1
(X,Y)	-2	-1	0	1	2





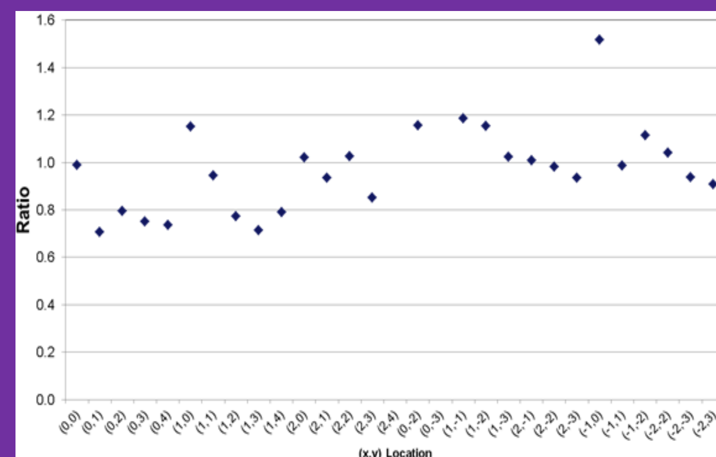
… and also *H**(10)



	H*(10) Rate (uSv/hr)				
4			1.4	1.5	1.6
3			1.8	2.0	2.3
2			2.7	3.4	4.1
1			4.8	7.0	8.6
0			10.0	26.7	30.4
-1			SOURCE	144.8	42.2
-2			141.3	75.4	35.5
-3			43.0	35.9	24.1
(X,Y)	-2	-1	0	1	2

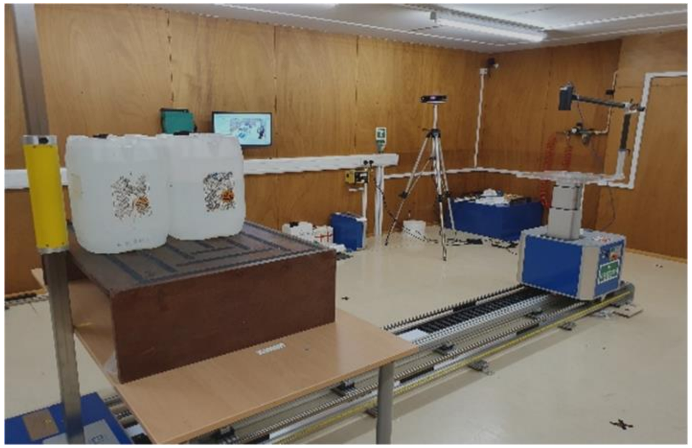
*H**(10) underestimates risk (i.e. *E*) by ~20%

µSv/h	Isd
(0,Y)	
0.58	0.01
0.73	0.01
1.09	0.01
1.87	0.02
4.05	0.03
SOURCE	
169.95	0.25
45.82	0.13



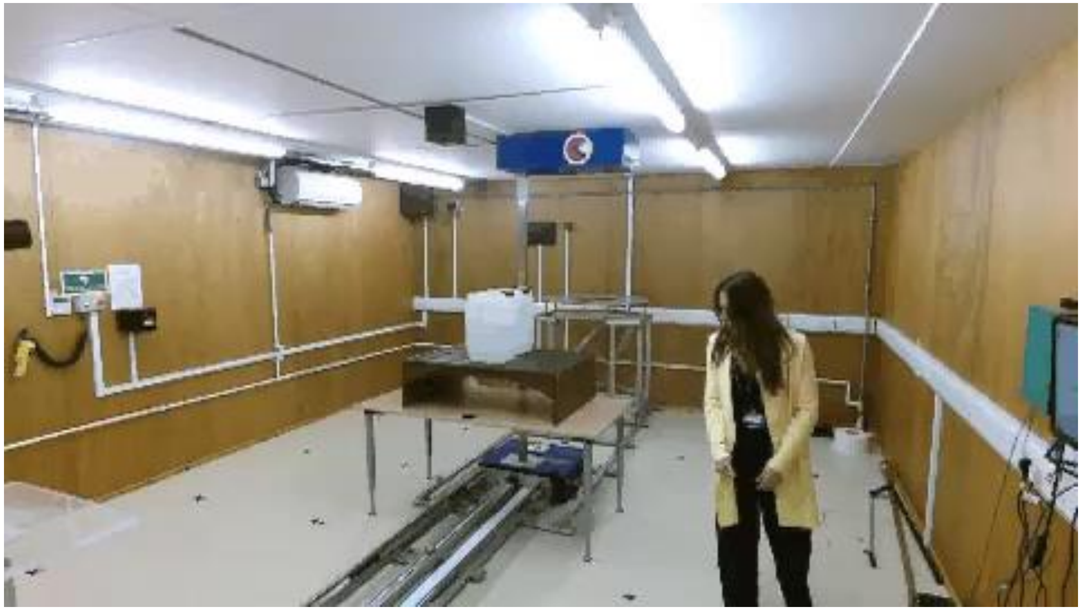
People Tracking

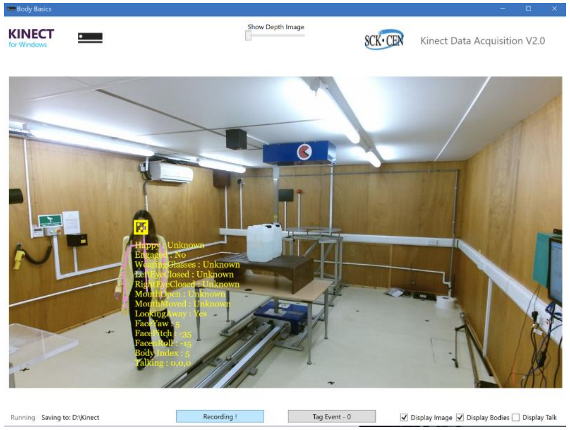
- Kinect camera set-up in laboratory to track people in real-time…

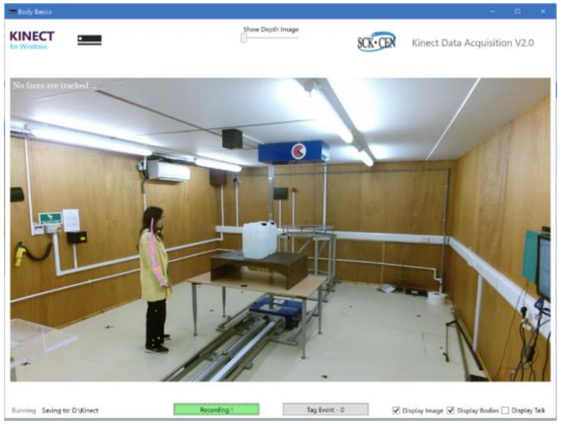


People Tracking

- Kinect camera set-up in laboratory to track people in real-time…



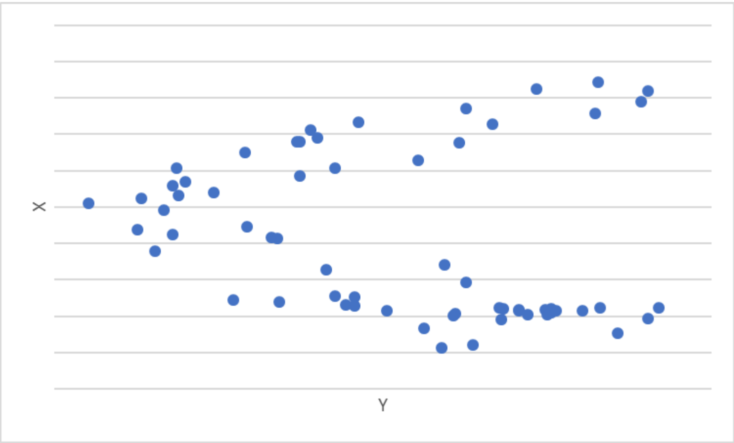




Tracking Output File (1s capture)
+ Dose Rate Map (1m × 1m grid)
+ Dose Conversion Algorithm

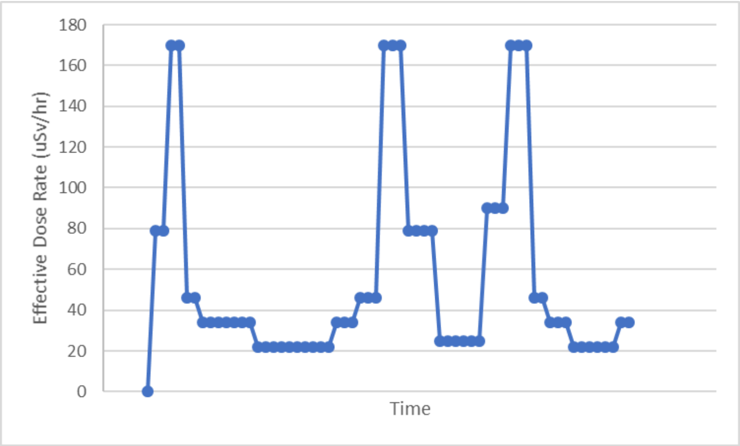
→ **"Dose" Data!**

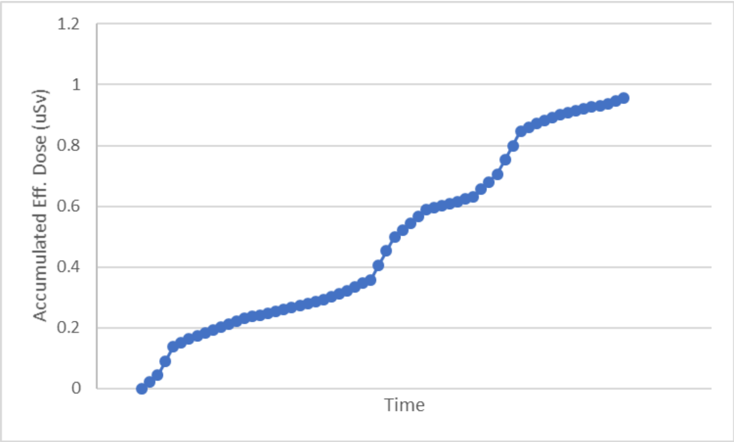
People Tracking: 1 minute test



Dose Rate:	uSv/hr	1sd	uSv/hr	1sd	uSv/hr	1sd	
	(0,Y)		(100,Y)		(200,X)		
	0.56	0.01	0.61	0.01	1.59	0.03	(X,400)
	0.73	0.01	0.83	0.01	1.40	0.02	(X,300)
	1.13	0.02	1.44	0.02	2.91	0.03	(X,200)
	1.96	0.02	4.48	0.04	7.34	0.05	(X,100)
	4.32	0.03	25.86	0.09	30.20	0.10	(X,0)
	SOURCE		174.54	0.26	46.39	0.13	(X,-100)
	79.13	0.12	77.01	0.18	33.50	0.12	(X,-200)
	23.06	0.07	33.15	0.12	21.68	0.09	(X,-300)

(+7 others)



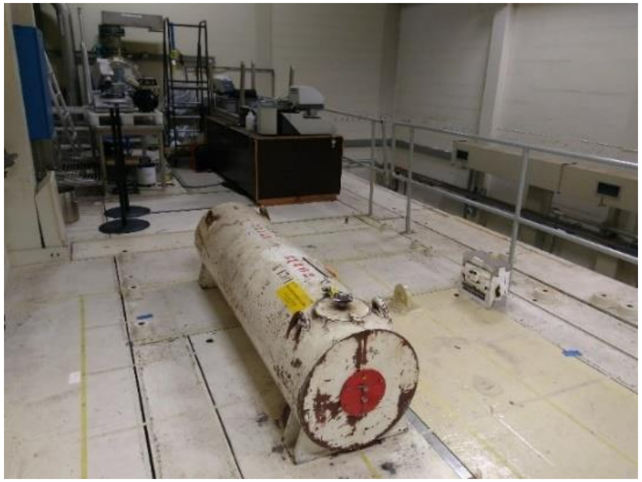


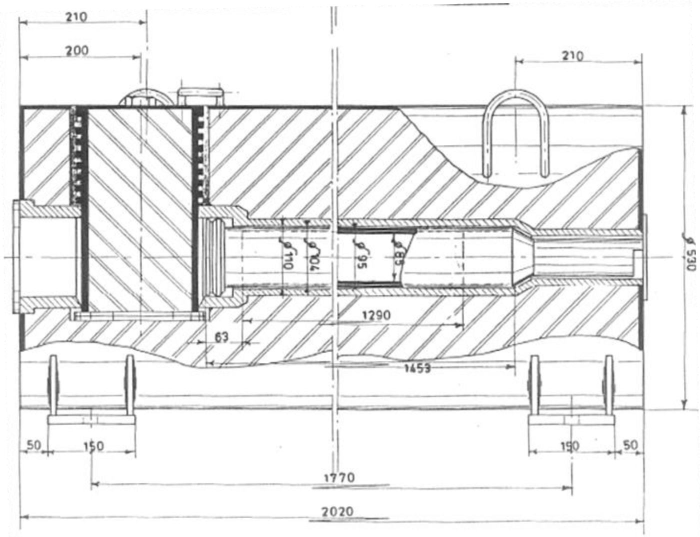
Effective dose ~1μSv in ~1minute ⇒ 60 μSv/hr average

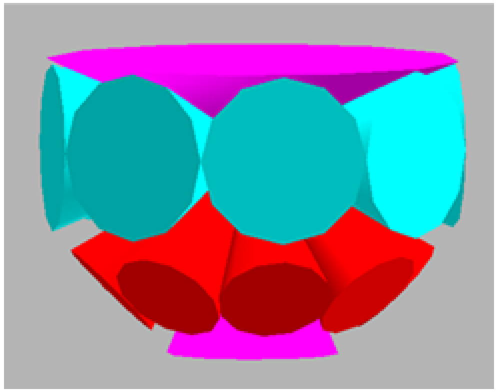
Ex2: SCK CEN Workplace Field

- UKHSA simulated field rather contrived… *useful also to consider a more realistic workplace scenario*
- Test in real workplace field at SCK CEN
- Features MOX spent fuel-flasks on concrete platform

Particularly challenging: Precise source composition / geometry unknown!

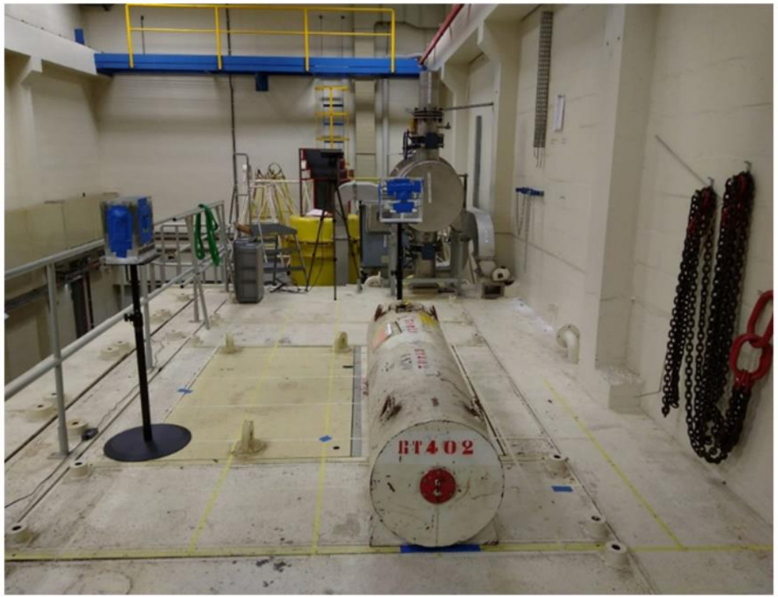


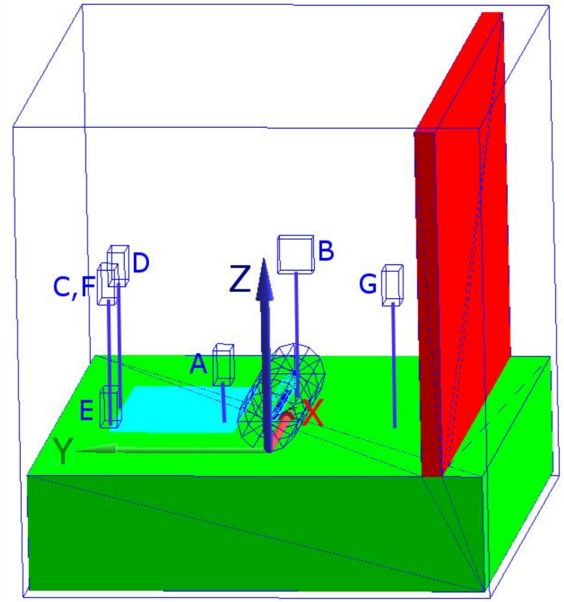




- Consider also standing, bending and kneeling individuals
  - ⇒ Need E/Φ for 45° downwards and map for different heights

Neutron field: SCK CEN

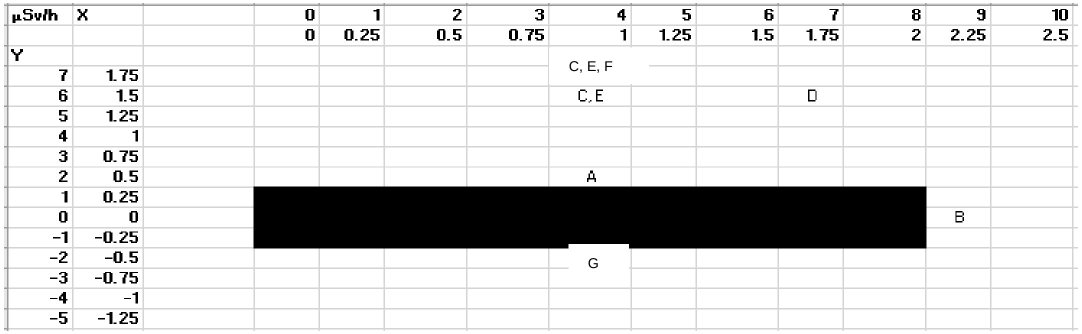




Build MCNP model to generate dose rate maps + fluence distributions

Use plausible guess spectra + geometry for source

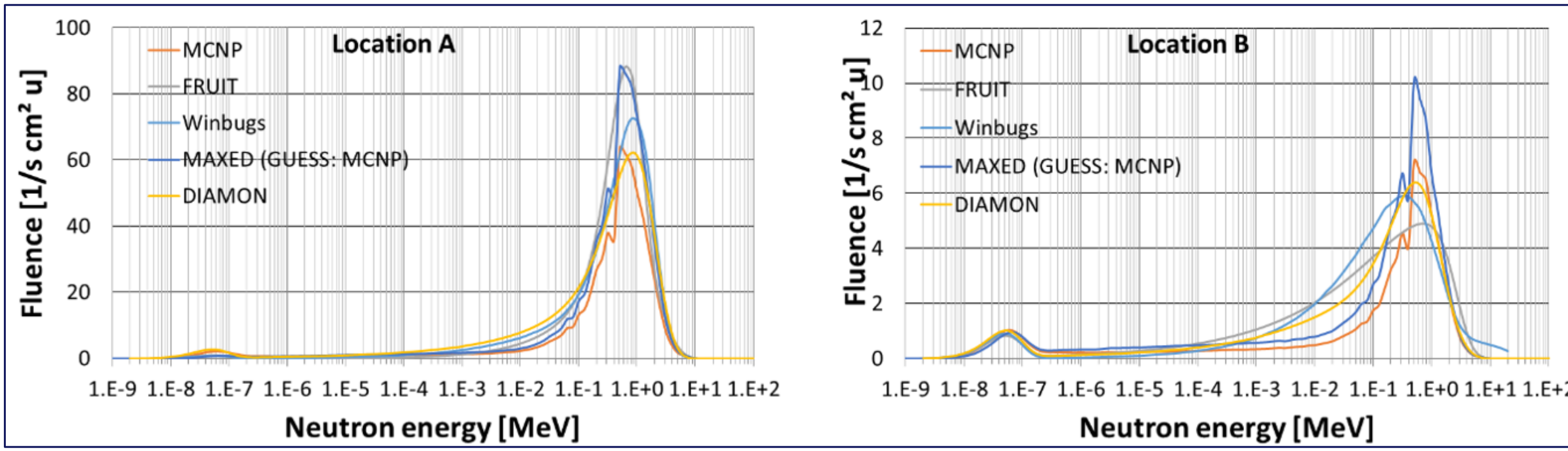
→ *Iterative approach*



50×50cm² (*x*,*y*) grid, heights: 18, 55 and 125 cm

Measurements & Modelling

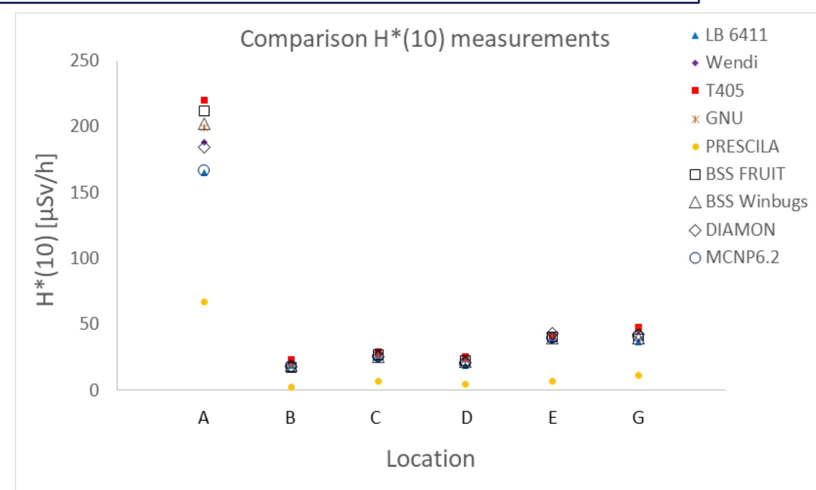
Benchmark MCNP data against ***H*(10)*** measurements and **spectrometry**… Variety of instruments and techniques applied



- Guess spectrum approach for source term successful!

  ⇒ Further iteration of source likely to give even better agreement

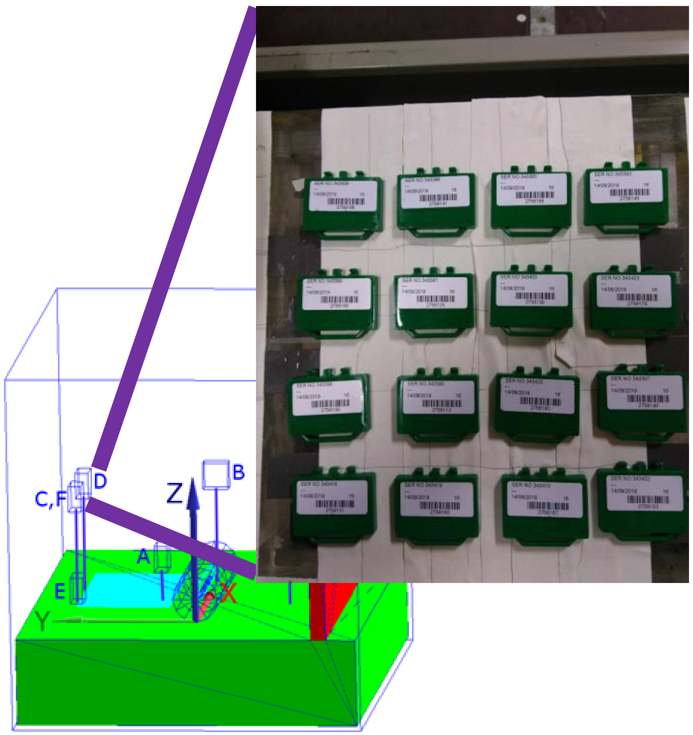
- Good agreement with most survey instruments… though not all perform well anyhow !

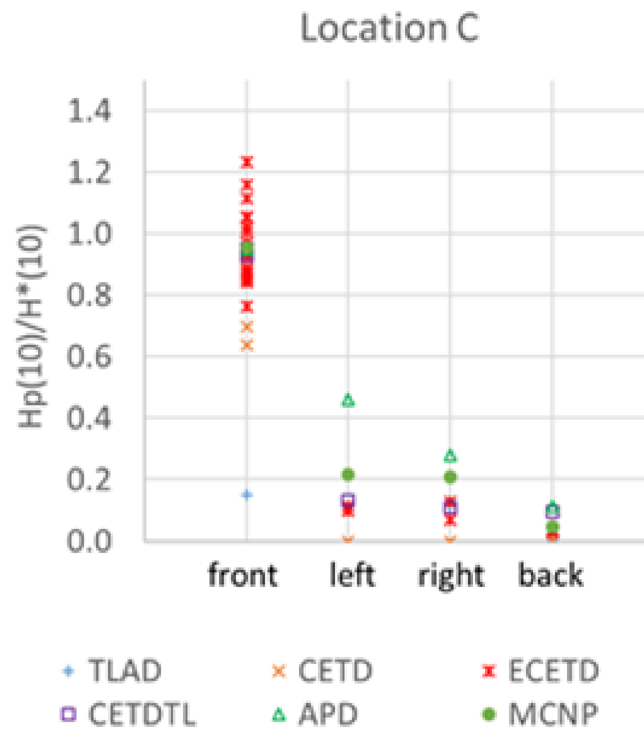


H_p(10) Assessments

Dosemeters placed on different surfaces of phantoms at locations

- 5 different types used: PADC (CE, ECE), Albedo TLD, EPD
- Array of PADC dosemeters also used across ‘front’ face





Position C: Hp(10)/H*(10)

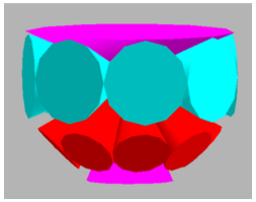
0.86	0.86	1.06	0.94
0.87	0.95	0.77	1.06
0.98	1.12	0.93	-
1.02	1.24	1.03	1.17

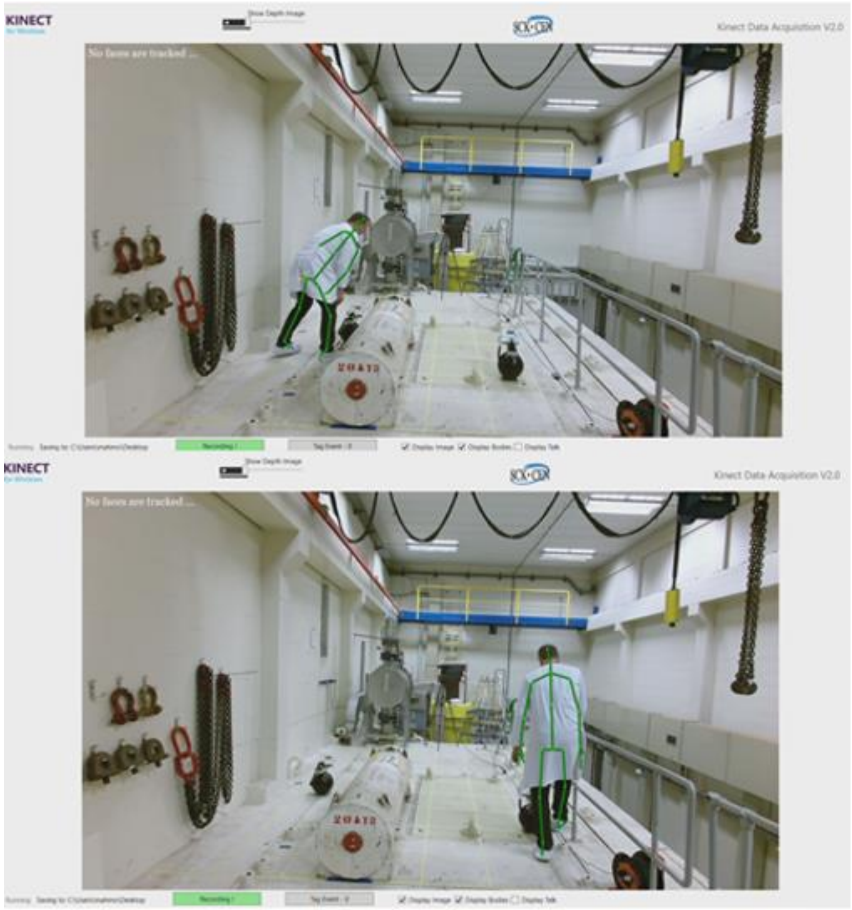
[Normalized to H(10) from MCNP or Bonner spheres]*

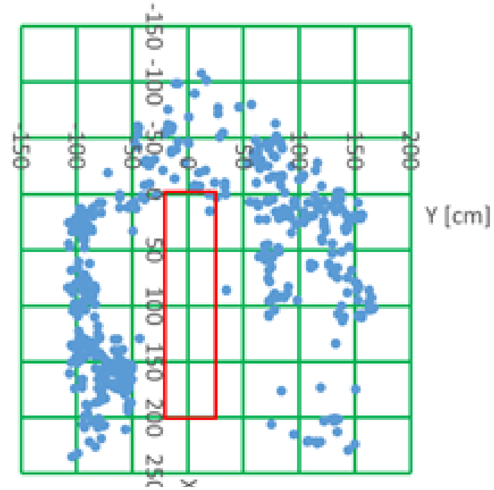
Personal dosemeter response varies greatly with type and position…

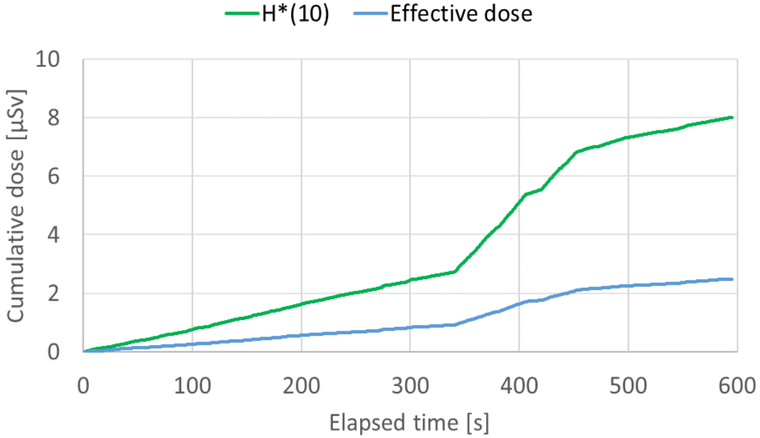
Worker dose rates: 10 minute test

Once model confirmed, calculate *E(x,y,z,θ)* and include in worker tracking package…









Summary

- Real-time neutron Monte Carlo not yet achievable…

  …***but estimating real-time doses is feasible***

  ⇒ **Effective dose rate maps + people tracking**

- Tests at UKHSA and SCK CEN demonstrated success of approach
- Survey instruments used to validate / scale the Monte Carlo models (*Personal dosemeter measurements also performed*)
  - Generally good agreement
  - Some inconsistencies in measurements shown up…
- Avoids some problems of using dosemeters and operational dose quantities
  - In the future, focus may shift more towards **protection quantities**
- PODIUM approach can account for dose rates well-below anything achievable by personal dosemeters (~nSv/s)
- **Next step is to develop current proof-of-concept into real-world applications…**

PODIUM
Personal Online DosImetry Using CoMputational Dosimetry

This project has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 662287

EUROPEAN JOINT PROGRAMME FOR THE INTEGRATION OF RADIATION PROTECTION RESEARCH
CONCERT

Special thanks to all the PODIUM team and UKHSA / SCK CEN colleagues…

PODIUM
Personal Online DosImetry Using CoMputational Dosimetry

This project has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 662287

EUROPEAN JOINT PROGRAMME FOR THE INTEGRATION OF RADIATION PROTECTION RESEARCH
CONCERT

- *J. Eakins, M. Abdelrahman, L. Hager, J. TM. Jansen, E. Kouroukla, P. Lombardo, R. Tanner, F. Vanhavere and O. Van Hoey* (2021). **VIRTUAL ESTIMATION OF EFFECTIVE DOSE IN NEUTRON FIELDS**. J. Radiol. Prot. 41(2). {doi: 10.1088/1361-6498/abf3b0}

- *O. Van Hoey, M. Abdelrahman, F. Vanhavere, P. Lombardo, J. Eakins, L. Hager, J. TM. Jansen and R. Tanner* (2022). **COMPUTATIONAL PERSONAL DOSIMETRY AT A REALISTIC NEUTRON WORKPLACE FIELD**. Rad. Meas. [*In Press*]. {doi: 10.1016/j.radmeas.2022.106867}

QUESTIONS?