UTILISATION OF THE MONTE-CARLO CODE 'MCBEND' AND THE DETERMINISTIC CODE 'ATTILA' TO ASSIST WITH THE SHIELDING AND DOSE ANALYSIS FOR THE LAND AND MARINE TRANSPORTATION OF AN INTERNATIONAL TRANSPORT FLASK

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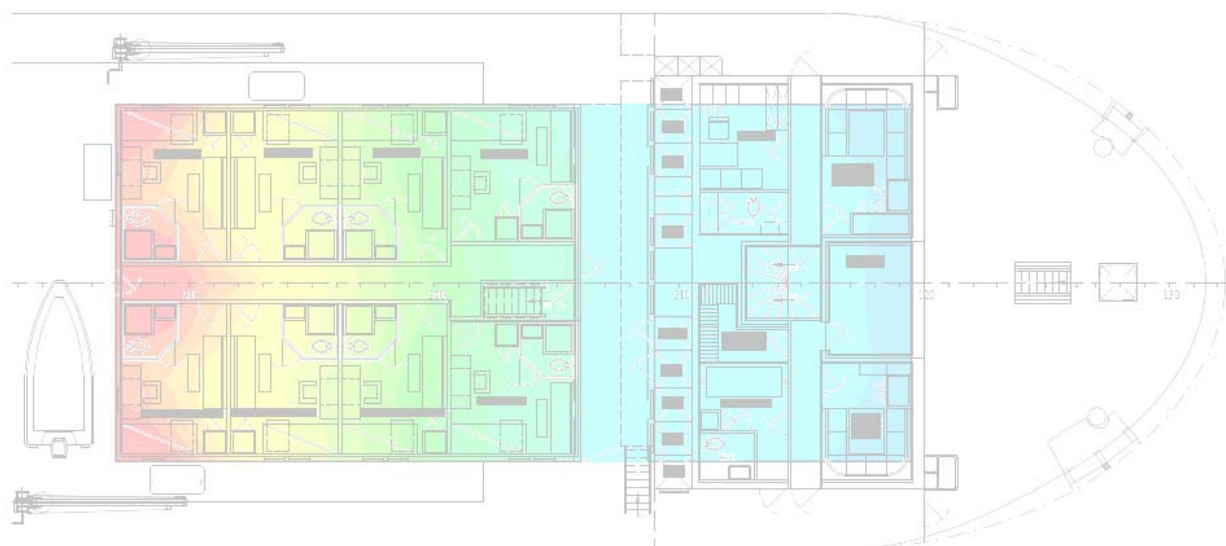

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Introduction

- Shielding / Dose Assessment required for International Transportation of MOX fuel

- Dose rate / uptake targets stipulated by IAEA
  - i. 10mSv/h at flask surface
  - ii. 100 μ Sv/h at 2m from vehicle
  - iii. <1mSv per year (to public) to avoid requirement for monitoring
  - iv. ALARA

- Approaches for solving the Transport Equation
  Stochastically: Probabilistic method (i.e. Monte Carlo)
  Deterministically: Solves using numerical methods such as Discrete Ordinates (SN)

- With sufficient refinement should converge on the same solution for neutral particle transport

Attila – Deterministic Radiation Transport Code

• **Discrete ordinates methods** solves transport equation by breaking down problem into discrete components of:

Space: Computational Meshes (spatial elements)

Angle: Angular components of flux

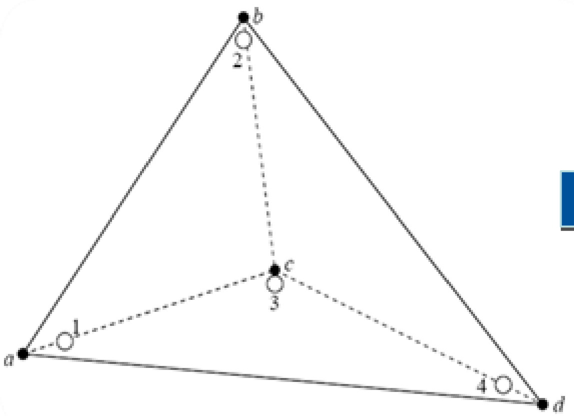
Energy: Multigroup Energy Formulation

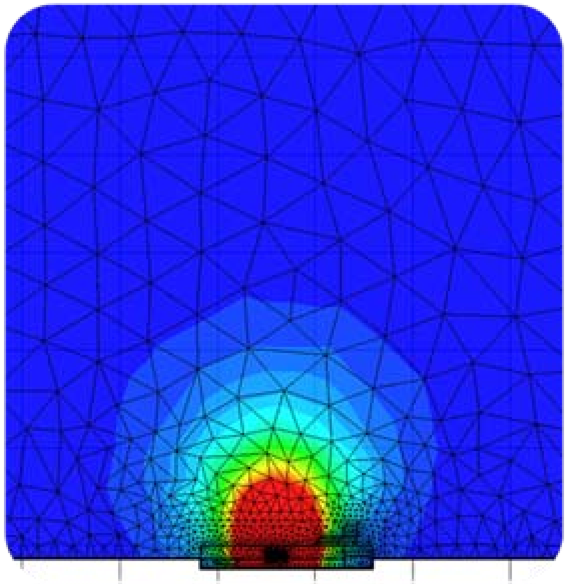
• Iteration of solution (increasing / refining the discretisation of **space, angle and energy**) required

• Code solves radiation transport equation for **angular** and **energy** dependent flux for each of the **spatial elements** throughout computational mesh

• Key advantage of discrete ordinates code → obtain a solution of the flux through out the problem (assess adequacy of shielding provisions → post processing contour plots)

Attila - Finite Elements

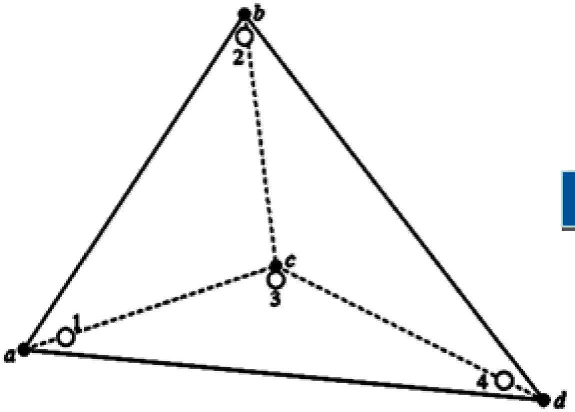


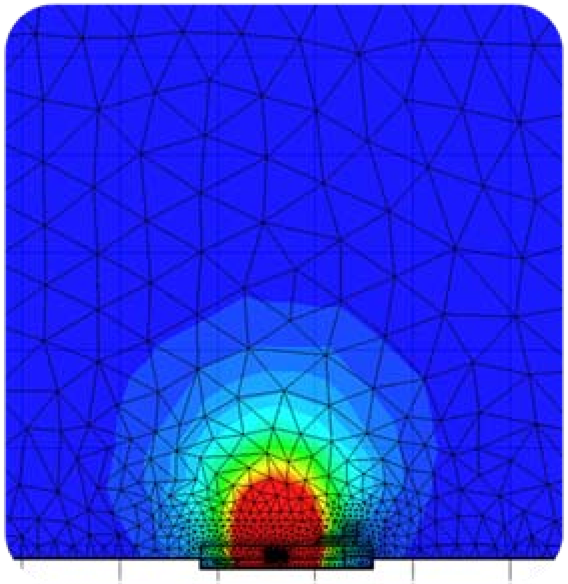


- Geometry reconstructed to a number of **finite elements** over which the transport equation solved

- Flux moments stored at nodes of each cell (O_1, O_2, O_3, O_4)

Attila - Finite Elements





- Geometry reconstructed to a number of **finite elements** over which the transport equation solved

- CAD generated model imported and converted to unstructured mesh consisting of **tetrahedral** elements

- Flux moments stored at nodes of each cell (O_1, O_2, O_3, O_4)

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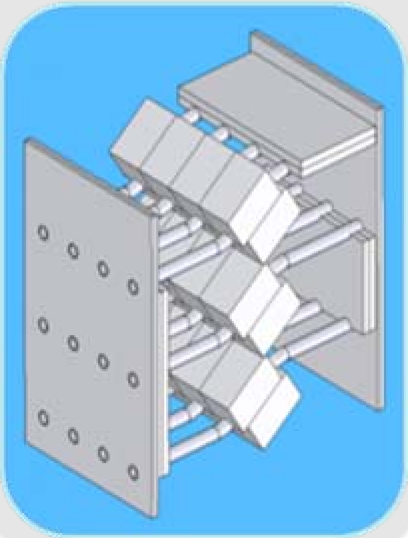
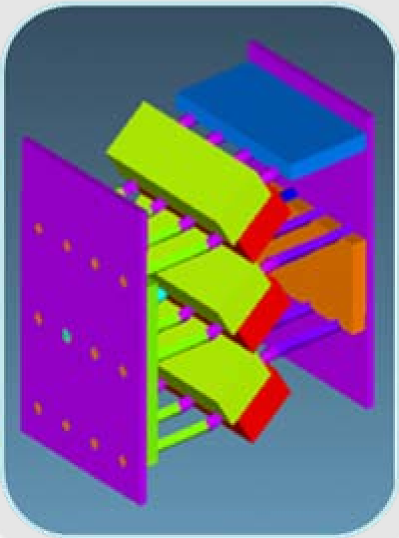
Attila - Finite Elements

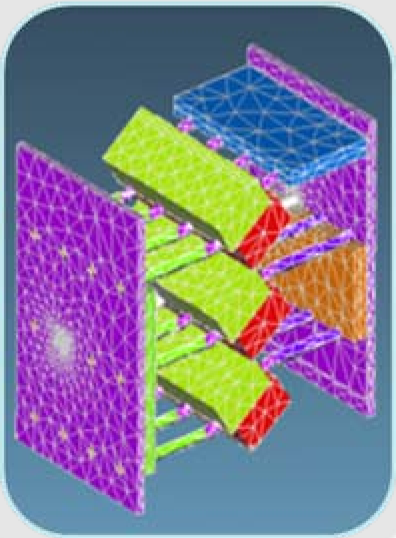
CAD Model



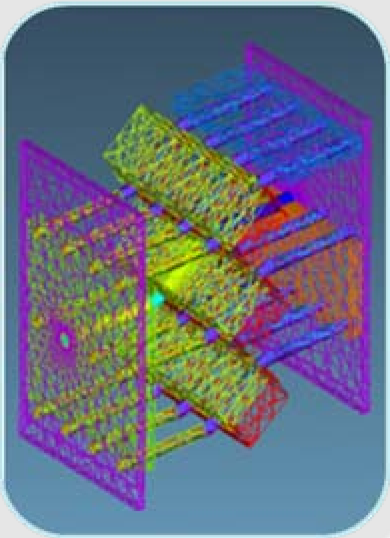
Solid Body



Tetrahedral Mesh



Wire Frame Mesh



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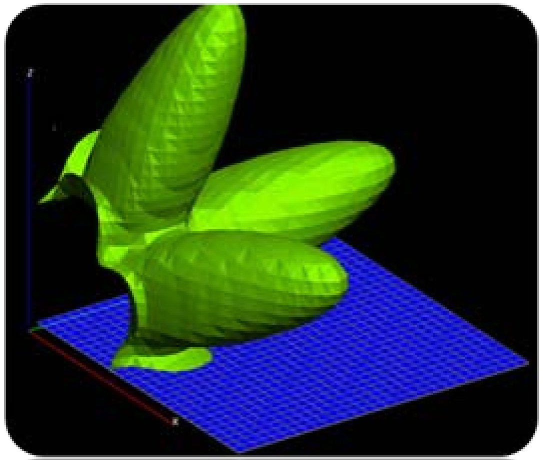
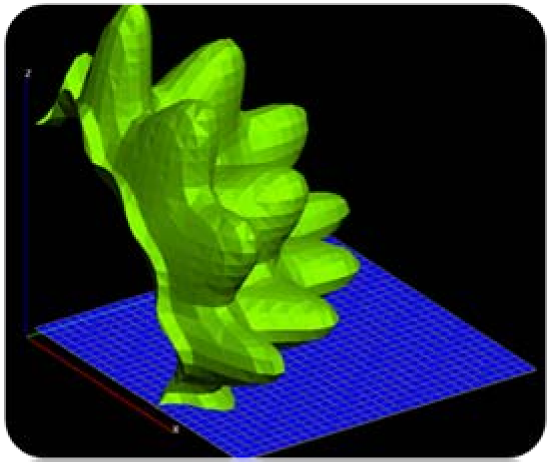
Attila - Angular Discretisation

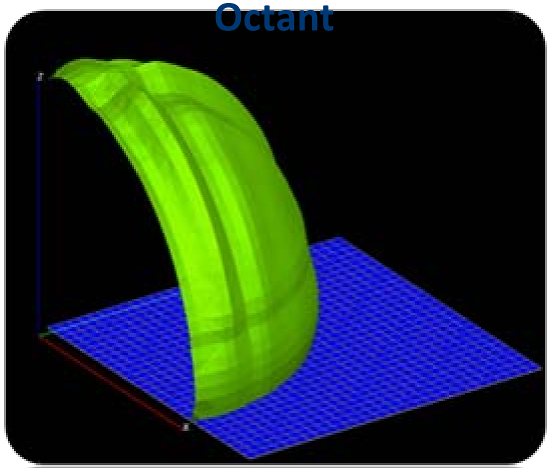
S_4 – 3 Ordinates per Octant



S_8 – 10 Ordinates per Octant



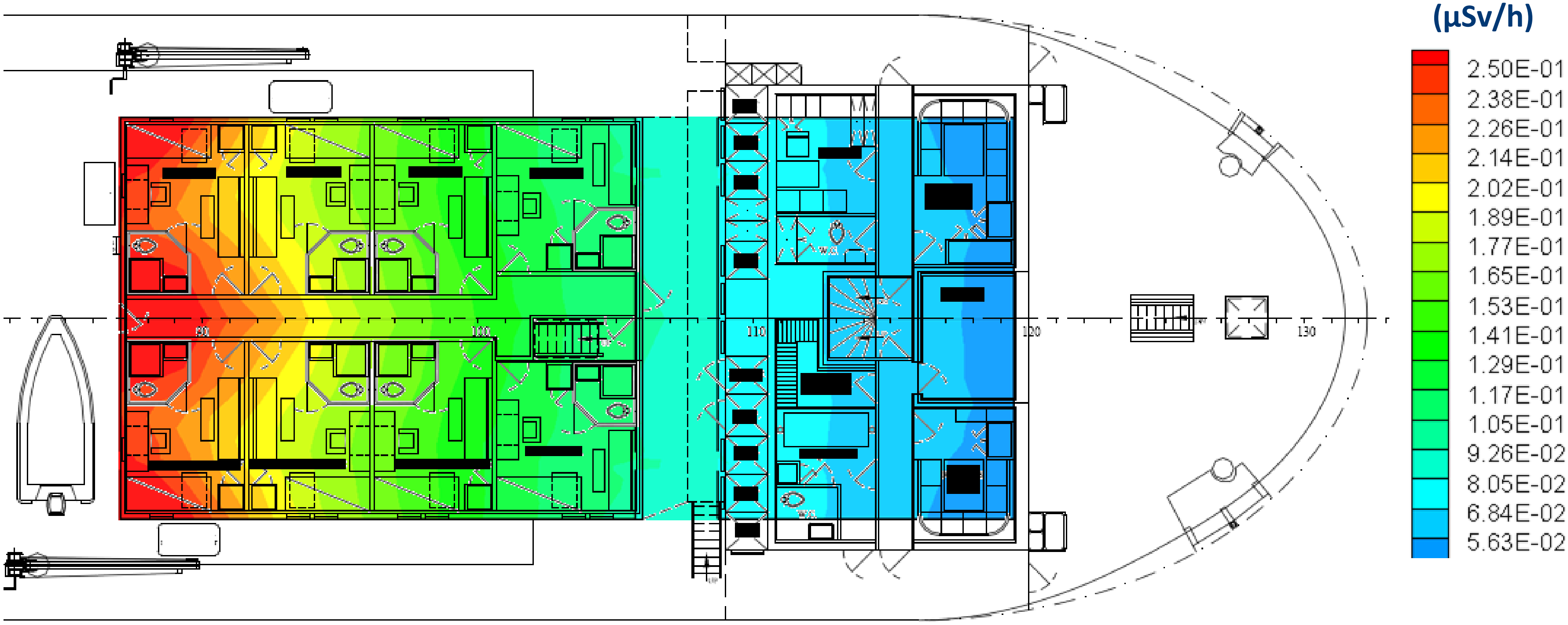
S_{16} – 36 Ordinates per Octant



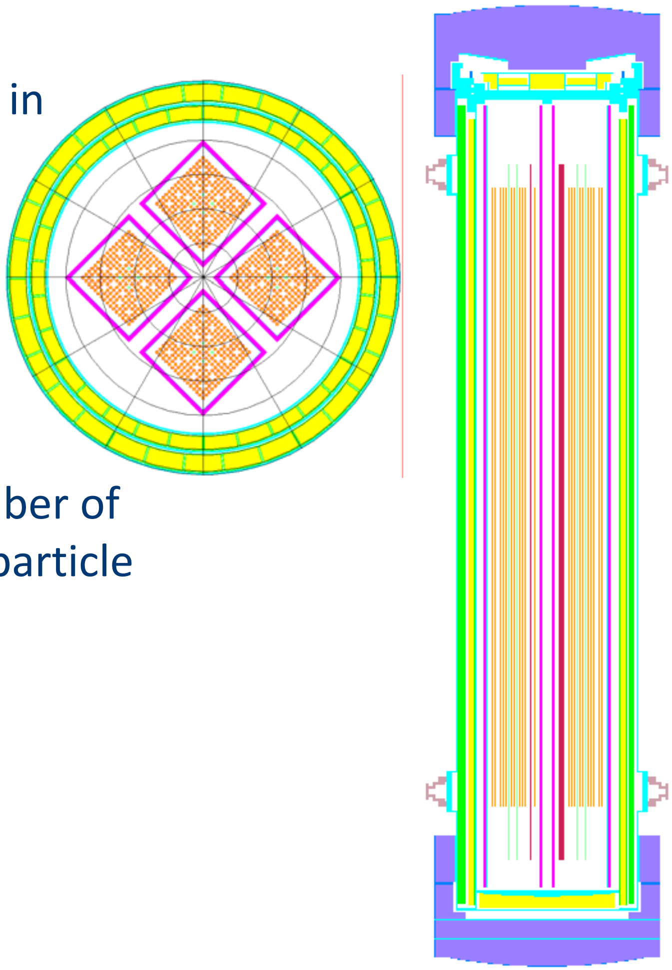
Ray effects

from a source in low density material (no scattering outside of source)

Attila – Post-processing



MCBEND – Monte-Carlo Radiation Transport Code



- Monte-Carlo methods used to calculate dose rates in **predetermined locations**

- Faster processing time than Attila

- HOWEVER for low statistical uncertainty, high number of particles required at ROI (shielding aim is to **reduce** particle flow)

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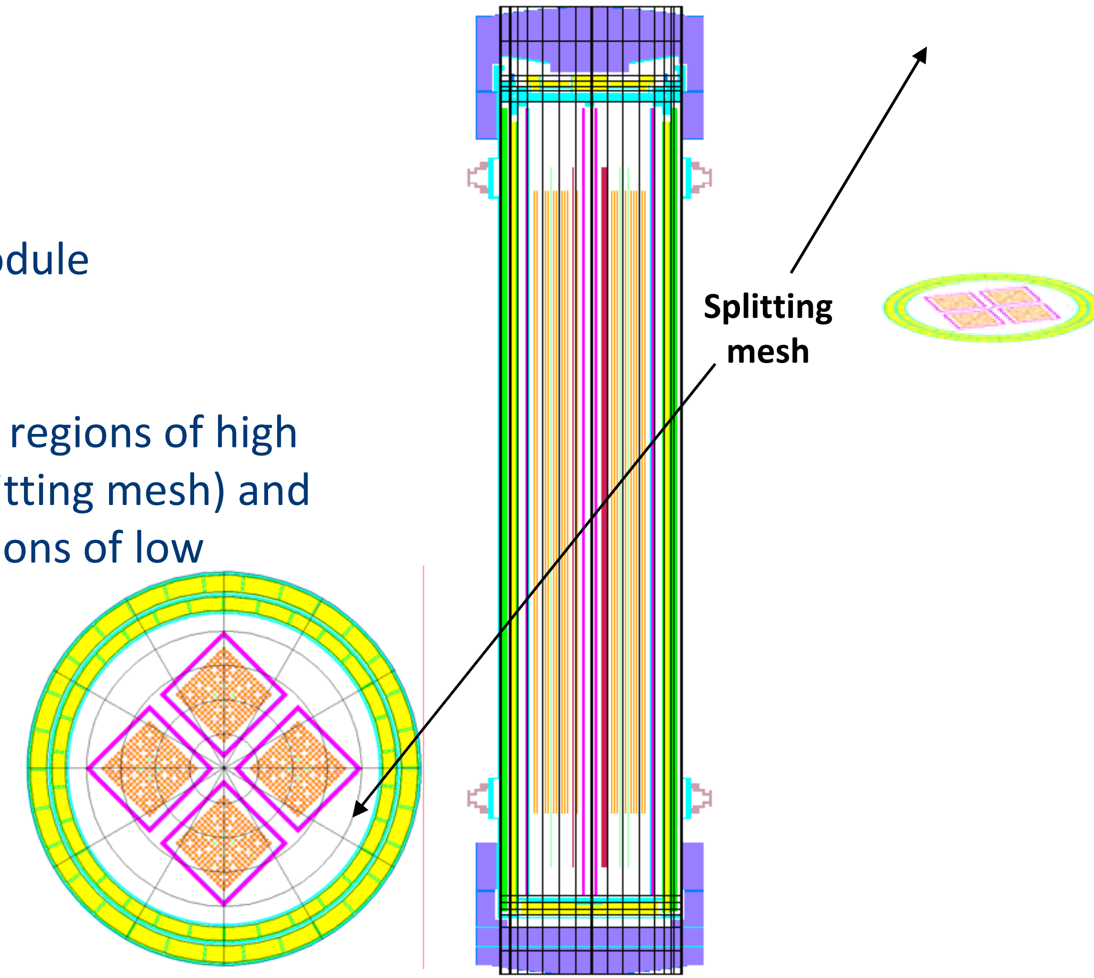
Calculation Methods – MCBEND Dose Rates around the Flask

Case 1 – Standard flask model

- Acceleration using MAGIC module

- Particles accelerated towards regions of high importance (selected in the splitting mesh) and ‘killed’ if travelling towards regions of low importance (saving CPU time)

- Allowance made for back-scatter



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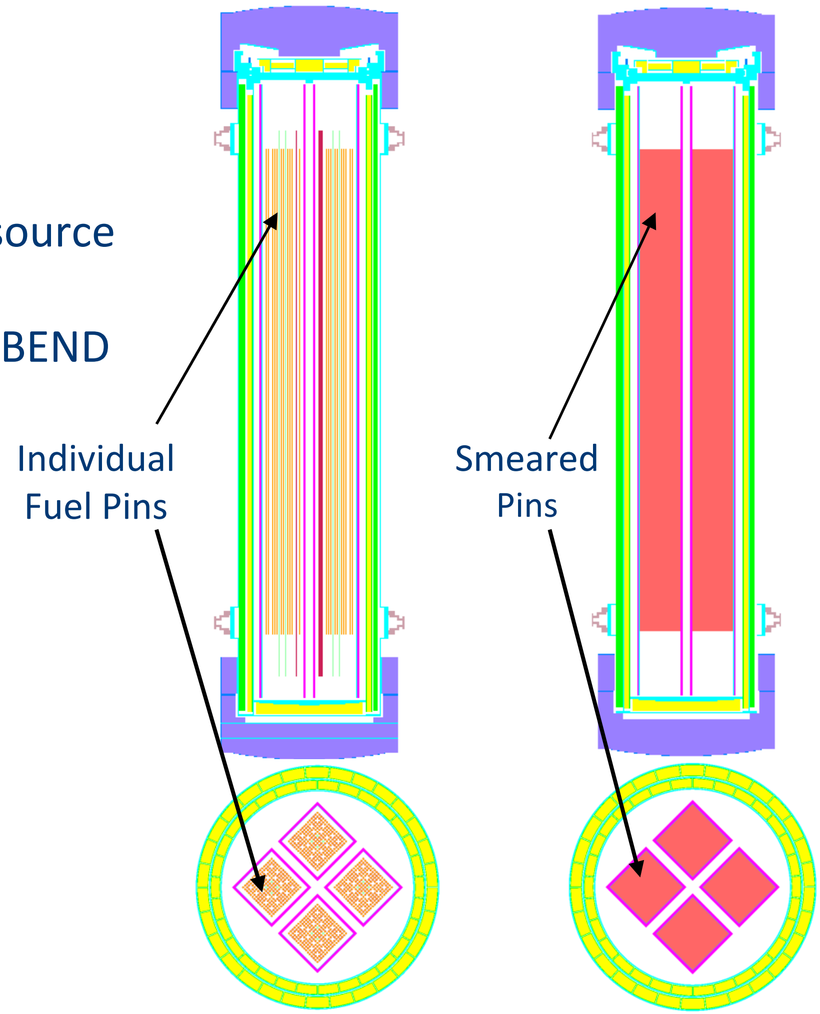
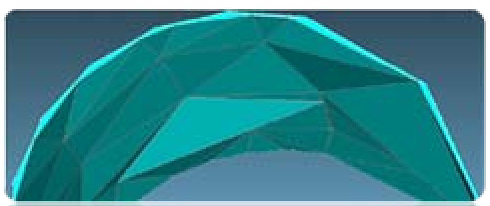
Calculation Methods – MCBEND Dose Rates around the Flask

Case 2 – Smeared source flask model

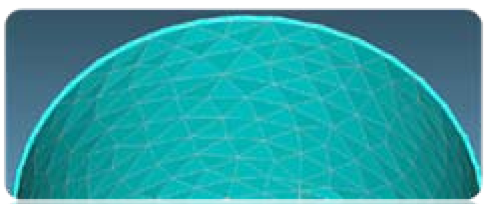
- Recognised that Attila would require smeared source

- Unsmeared and smeared cases executed in MCBEND for comparison





Poor resolution of annular region in Attila



Improved resolution of annular region in Attila at expense of increased cell count

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Calculation Methods – MCBEND Dose Rates around the Flask

Case 3 – Leakage File Calculation

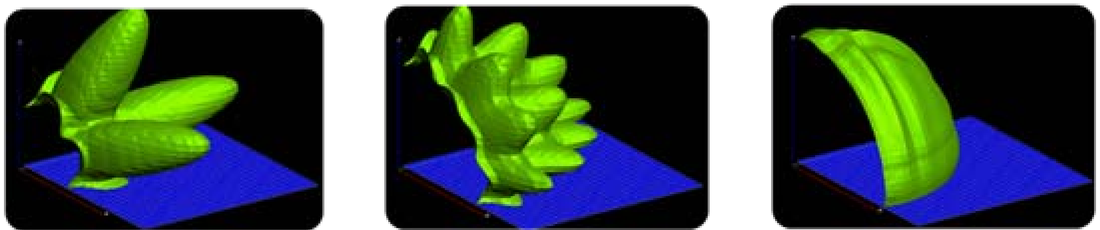
- Recognised that ship calculation would require **independent acceleration methods**

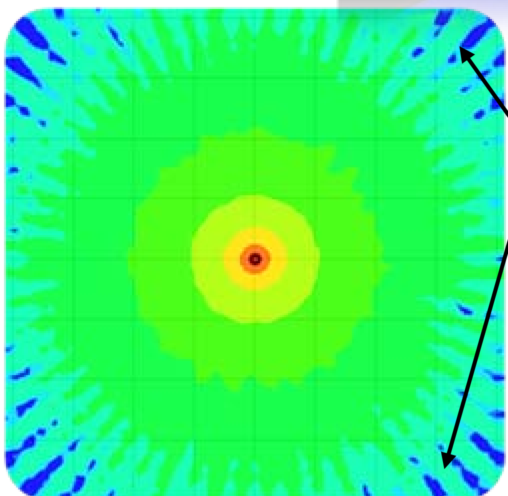
- Requirement to break down the ship calculation into two separate calculations
  - Primary flask '**Leakage File**'
  - Secondary Ship Calculation with '**Leakage Source**'

	Neutron Dose Rates (µSv/h)			Gamma Dose Rates (µSv/h)			Total Dose Rates (µSv/h)		
	Unsmeared	Smeared	Leakage	Unsmeared	Smeared	Leakage	Unsmeared	Smeared	Leakage
Contact	129.0	137.0	143.8	29.6	32.9	30.6	158.6	169.9	174.4
0.3m	73.6	75.1	77.1	17.4	19.4	17.6	91.0	94.5	81.8
1m	35.0	37.5	39.9	8.9	9.5	8.9	43.9	47.0	42.3
5m	4.7	4.9	5.5	1.2	1.3	1.2	5.9	6.2	5.8
10m	1.4	1.5	1.7	0.35	0.38	0.36	1.8	1.9	1.8
20m	0.37	0.38	0.43	0.09	0.10	0.09	0.46	0.48	0.45
50m	0.05	0.05	0.06	0.01	0.01	0.01	0.06	0.07	0.06

Calculation Methods – Attila Dose Rates around the Flask

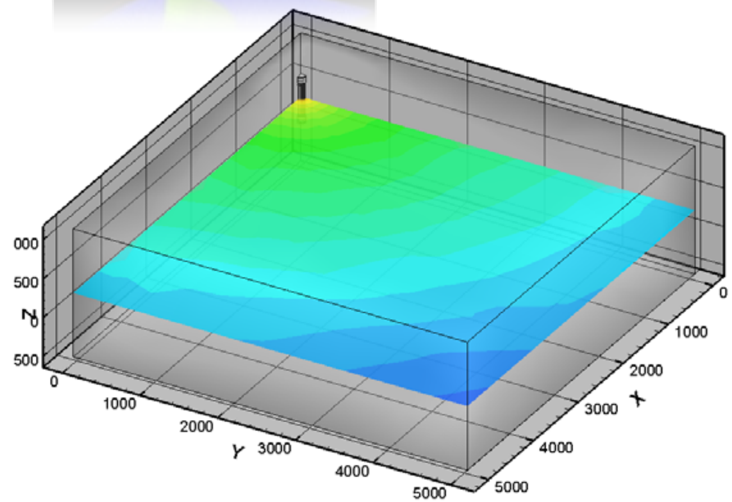
- Several iterations with optimised **spatial elements, angular discretisation** and **energy group structure**
- Increasing SN order until ray effects eliminated
- This maybe done at the expense of energy groups or cell count → OPTIMISATION



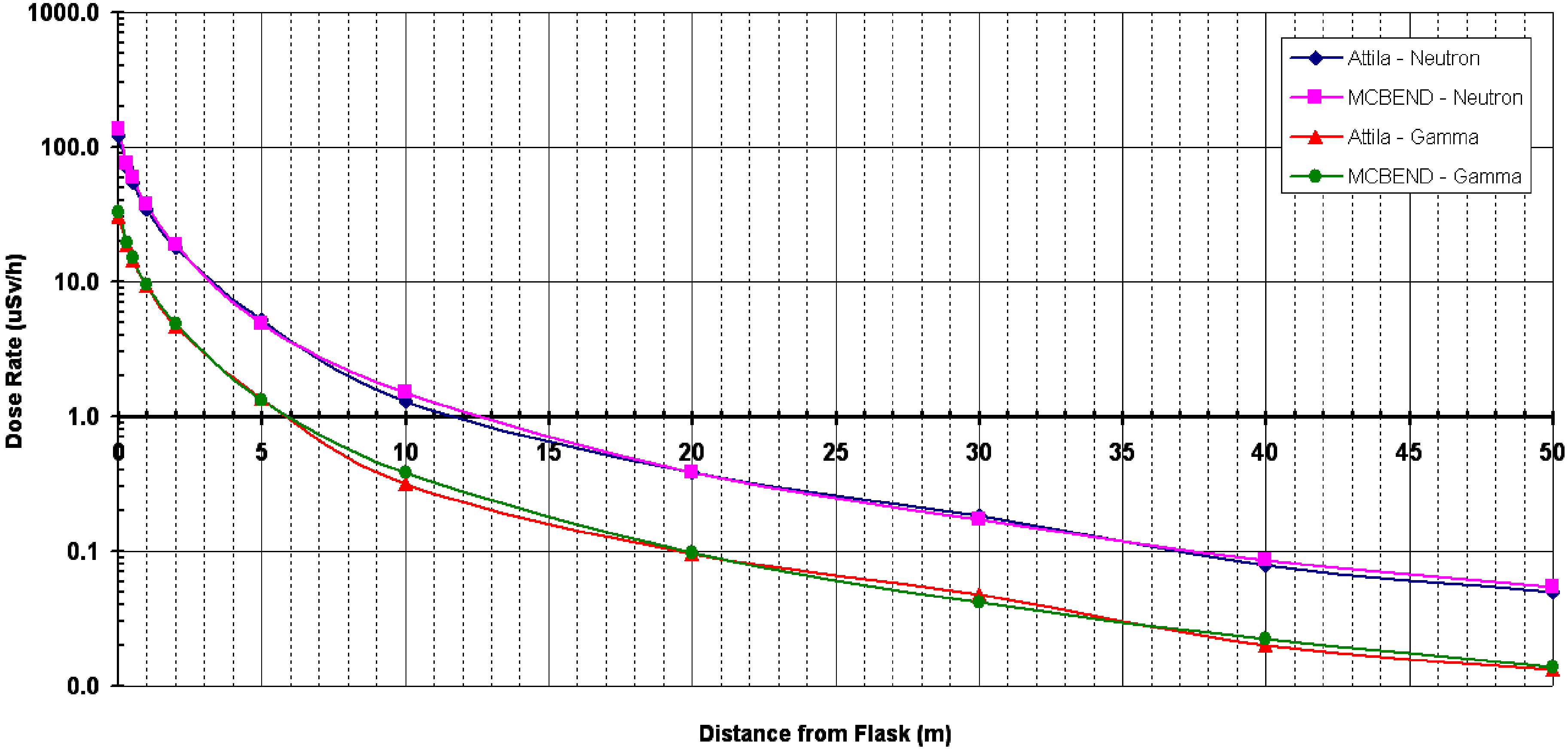


Low angular discretisation (SN) leads to ray effects in this case

SN = 28 provides smooth dose rate contours at large distances from the flask



Calculation Methods – Attila / MCBEND Flask Comparisons



Calculation Methods – MCBEND / Attila Dose Rates on Ship

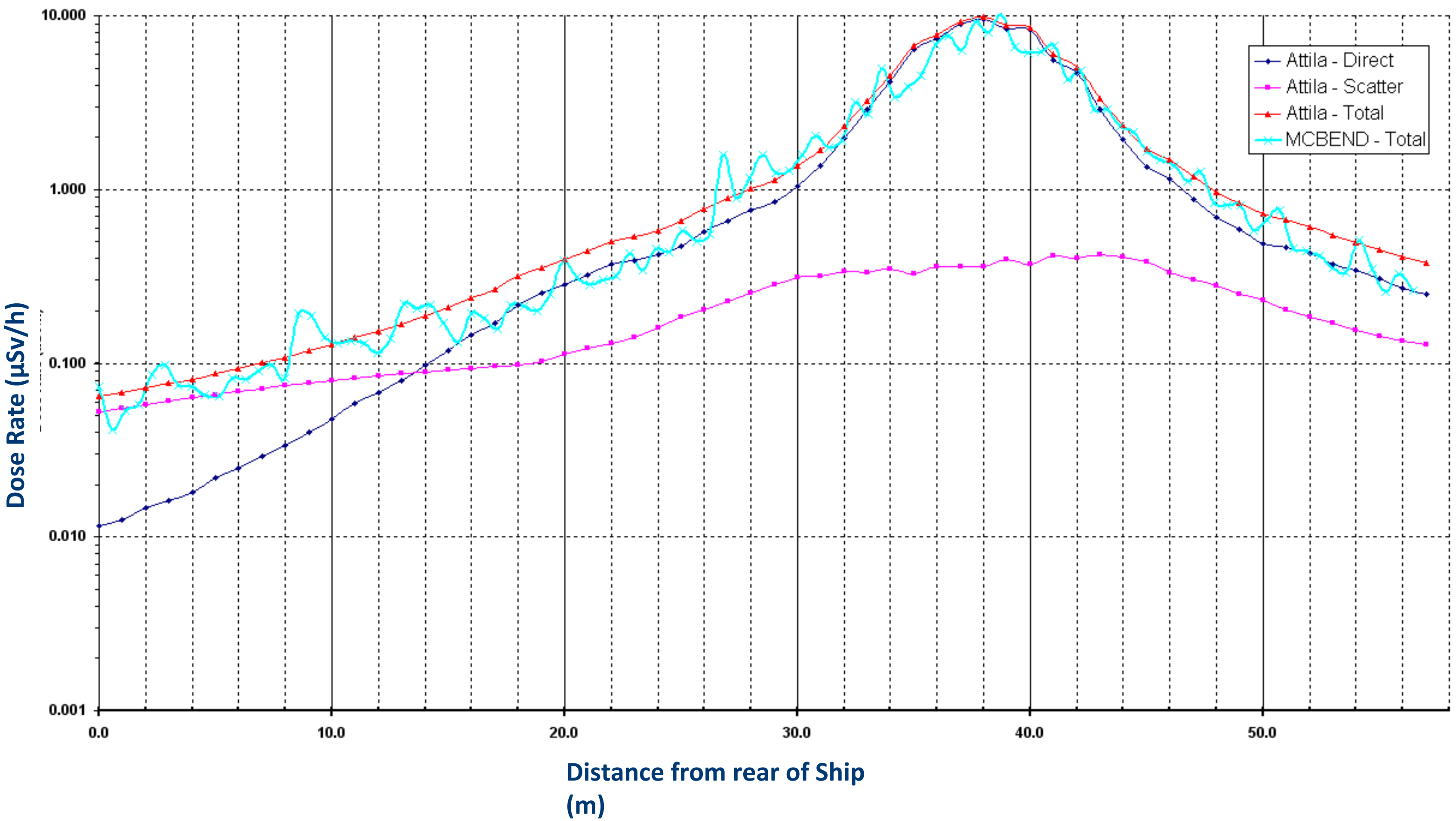
- MCBEND – Leakage file (1e+06 samples emerged at the surface) used
- Further acceleration required in gamma case (structural steel shielding on ship)
- Attila – ship modelled with optimisation of **spatial, angular, energy** elements

Scatter Sources……..

- Skyshine (100m x 100m x 500m)

- Water scatter

Effects of Skyshine and Sea Scatter



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Results – MCBEND Dose Rates at Key Locations

	Dose Point	Neutron Dose Rates (µ… Direct Component	Neutron Dose Rates (µ… Direct + Scatter	…a Dose …µSv/h) Scatter	Total Dose Rates (µSv/h) Direct + Scatter	Gamma Contribution
Weather Deck	DP 1	0.02	0.07	E-04	0.07	1%
	DP 2	0.02	0.06	E-04	0.06	1%
	DP 3	0.09	0.21	E-03	0.22	2%
	DP 4	0.08	0.17	E-03	0.17	2%
	DP 5	0.06	0.14	E-03	0.14	2%
	DP 6	0.05	0.11	E-03	0.11	1%
	DP 7	0.03	0.07	E-04	0.07	1%
	DP 8	0.02	0.06	E-04	0.06	1%
Deck A	DP 9	0.14	0.26	E-02	0.27	4%
	DP 15	0.09	0.22	E-03	0.23	3%
	DP 16	0.06	0.16	E-03	0.16	2%
	DP 17	0.05	0.13	E-03	0.13	1%
	DP 19	0.03	0.07	E-04	0.07	1%
	DP 20	0.02	0.06	E-04	0.06	1%
Deck B	DP 23	0.02	0.07	E-04	0.07	1%
	DP 24	0.01	0.05	E-04	0.05	1%
	DP 25	0.02	0.07	E-04	0.07	1%
	DP 26	0.01	0.05	E-04	0.05	1%
Deck C	DP 27	0.02	0.07	E-03	0.07	2%
	DP 28	0.01	0.05	E-04	0.05	1%
Engine Room	DP 31	0.12	0.23	E-03	0.23	2%

Scatter Contribution
67%
69%
56%
55%
55%
58%
64%
65%
46%
60%
63%
62%
65%
69%
68%
75%
73%
77%
76%
84%
46%

Neutron Contribution
99%
99%
98%
98%
98%
99%
99%
99%
96%
97%
98%
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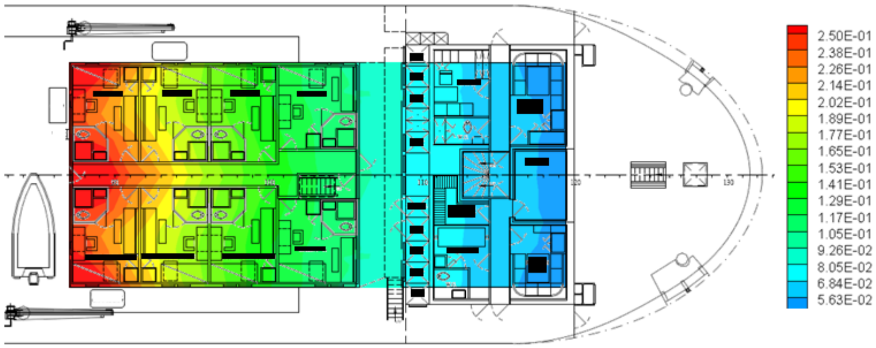
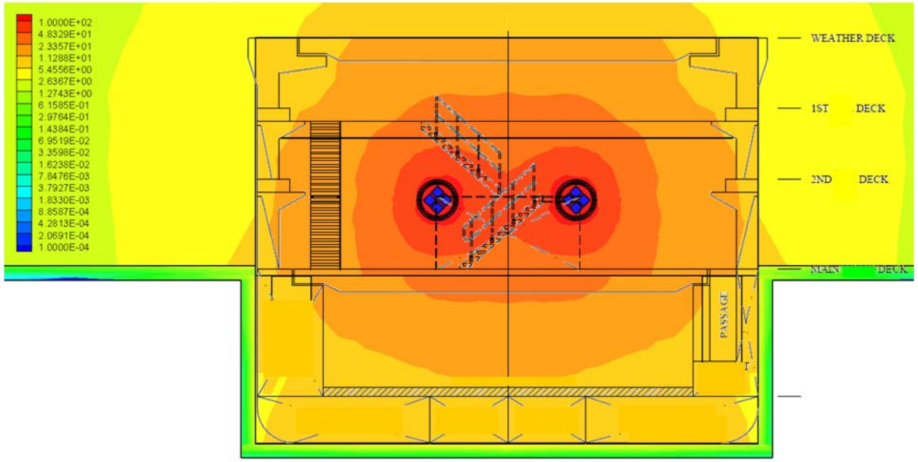
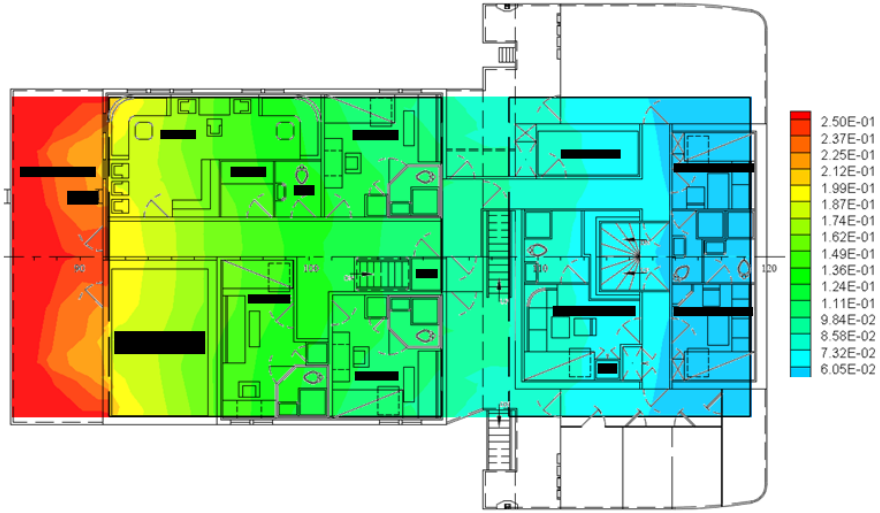
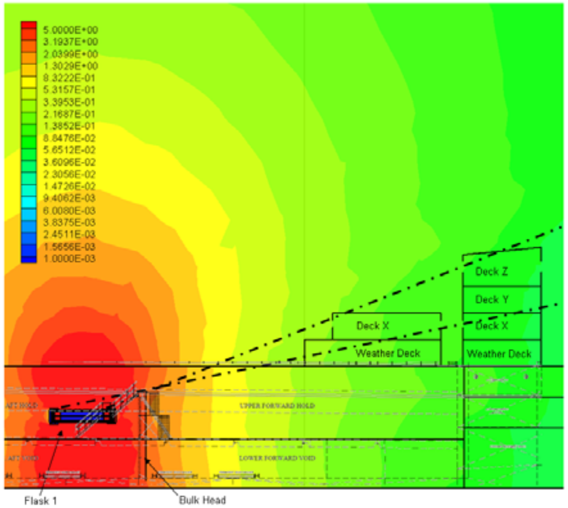
Results – Attila Dose Rates at Key Locations









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Results – Dose Uptake to Ship Crew

Worker Group	Committed Man-hours	Voyage man-hours (h)	Remaining man-hours	Individual Dose Uptake (mSv)
M	54.00	96	42.00	0.006
C/O	58.5	96	37.5	0.041
2/O	61.5	96	34.5	0.043
3/O	58.5	96	37.5	0.043
CPO	57	96	39	0.009
R	252.6	288	35.4	0.008
C/E	60	96	36	0.034
2/E	60	96	36	0.014
ETO	60	96	36	0.011
S	721.5	768	46.5	0.042
C	60	96	36	0.038

Totals	1279	1920	737	

Summary

- Dose rates calculated at key locations around the flask within IAEA criteria

- Dose uptake to ship crew within the criteria stipulated by the IAEA

- No requirement for additional shielding on the ship / vehicle

- No requirement to revise loading plan

- Crew able to undertake multiple voyages with similar radiation sources

Conclusions

Using both Monte Carlo and Deterministic methods:

- Provides Independent Calculation Methods;

- Provides a powerful means of crosschecking results (and therefore a high degree of confidence);

- Allows detailed modelling of geometry

- Gives a better understanding of the flux transport within a problem