

Point-kernel-based 3D ray tracing gamma dose rate calculator

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Outline

- Problem description
- Methodology
- GUI and Input preparation
- Ongoing developement
- Pros and cons

Problem description

- At ITER there is a complex time dependent neutron and gamma radiation field which is modeled with MCNP based simulations as standard
- This method is robust and accurate but demands significant time for model preparation/runtime/post processing
- However some of the components of the radiation field may be modeled with other means:
 - Point kernel based 3D ray tracing for discrete decay gamma sources like: TCWS ^{16}N or ACP sources
 - To have a tool where easy to check design changes, assess uncertainties independently

Methodology

- 3D point kernel method for dose rate calculation (monoenergetic):
 - $D(\bar{t}) = F * DCF * \sum_s I(\bar{s}) \frac{1}{4\pi r_s^2} \prod_i e^{-\rho_i \mu_i x_i}$
 - Where \bar{t} denotes the target point, F is an arbitrary factor, DCF is the dose conversion factor, \bar{s} denotes the source points, I is the intensity at each given source points, r_s denotes the distance between \bar{s} and \bar{t} , ρ_i denotes the density of the i^{th} material, μ_i denotes the mass attenuation coefficient of the i^{th} material and x_i denotes the thickness of the i^{th} material
- To determine the x_i the **PyVista** open source python ray tracing is used with stl geometry files

Methodology

- $D(\bar{t}) = F * DCF * \sum_s I(\bar{s}) \frac{1}{4\pi r_s^2} \prod_i e^{-\rho_i \mu_i x_i}$
- μ_i can be obtained from <https://www.nist.gov/pml/x-ray-mass-attenuation-coefficients>
- DCF values can be adjusted to values used in MCNP calculations
- $I(\bar{s})$ is an user input, for example the ^{16}N intensity along pipes
- ρ_i values can be adjusted to the values used in MCNP calculations
- r_s is trivial as the target and source points are all user inputs

GUI and Input preparation

The screenshot shows the 'Radiation Shielding GUI' with several sections:

- Bounding Boxes:** A table for defining source and target regions.
- Files:** Fields for Source CSV File, Target CSV File, and a checkbox for 'Write to Output CSV'.
- STL Files:** A list of material files with checkboxes, each associated with density and mass attenuation coefficient values.
- Additional Parameters:** Fields for Factor, DCF, and Air MAF* density.
- Run:** A button at the bottom.

Parameter	Value
Source X Min	368.468
Source X Max	2638.28
Source Y Min	-2555.2
Source Y Max	2385.27
Source Z Min	970
Source Z Max	1651.27
Target X Min	3475
Target X Max	4300
Target Y Min	-1710
Target Y Max	-910
Target Z Min	641
Target Z Max	1024

Field	Value	Action
Source CSV File	source_intensity.txt	Browse
Target CSV File	TKC_voxel_centers.txt	Browse
Write to Output CSV	None	Browse

File Name	Density	Mass Attenuation Coeff
<input type="checkbox"/> TCWS_lead_coarse.stl	11.35	0.04675
<input type="checkbox"/> TKC_Heavy_concrete_coarse.stl	3.6	0.02432
<input type="checkbox"/> B2+B1+L1+L2+L3+L4-5_NC_merged.stl	2.2	0.02432
<input type="checkbox"/> Backfill+cable_tray_NC_coarse.stl	2.0	0.02432
<input type="checkbox"/> TKC_steel_coarse.stl	7.874	0.02991
<input type="checkbox"/> TCWS_Pipes_coarse.stl	7.874	0.02991
<input type="checkbox"/> TCWS_water_coarse.stl	1.0	0.02429
<input type="checkbox"/> TCWS_004_CVBD_NOVASHIELDING_coarse.stl	8.0	0.04675
<input type="checkbox"/> TCWS_Concrete_corase.stl	2.2	0.02432

Parameter	Value
Factor	1
DCF	0.000000769
Air MAF* density	0.00002681125

User can restrict the source and target ROI

Source points and intensities as csv e.g.:
x,y,z,intensity
2619.00259,1680,1433,1.22E+16

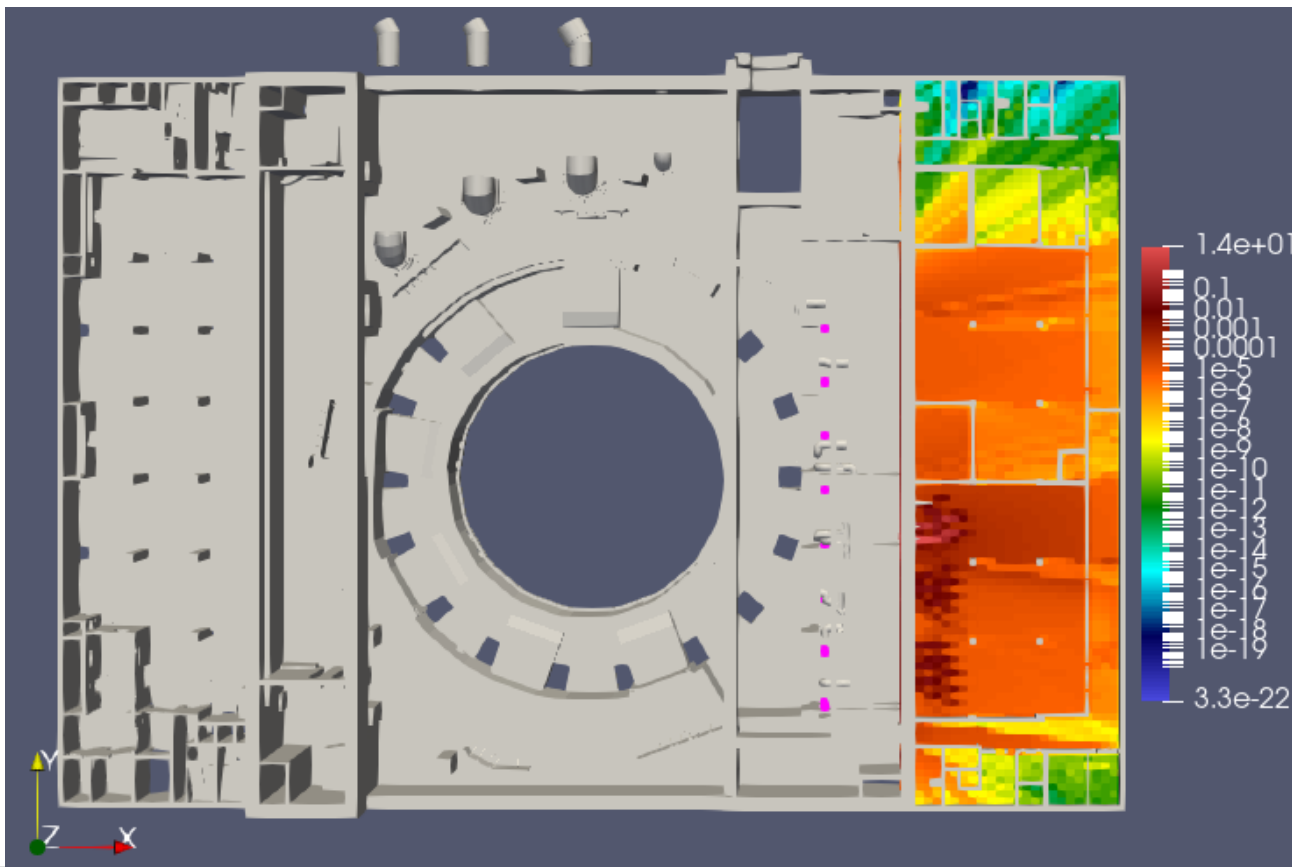
Target points as csv

Each material should be represented by a separate stl file
-Watertight, avoid overlapping regions
-it is possible to assign the density and mass attenuation coefficient for each material (geoemtry)

-F factor can be used, for build up or for safety factor
-DCF for the gamma energy of interest
-The VOID not defined in the geometry files is assumed to be air → Air mass attenuation coefficient*Air density should be set

PRELIMINARY! Output example

- Output is a vtk file



Performance for
24 source points at UPC
18928 target points:
~3.5 hours with 8 cores
Using geometries:
-TKC NC structures,
-TKC HC structures,
-TKC Steel structures
-Backfilling+cable tray

Ongoing developement

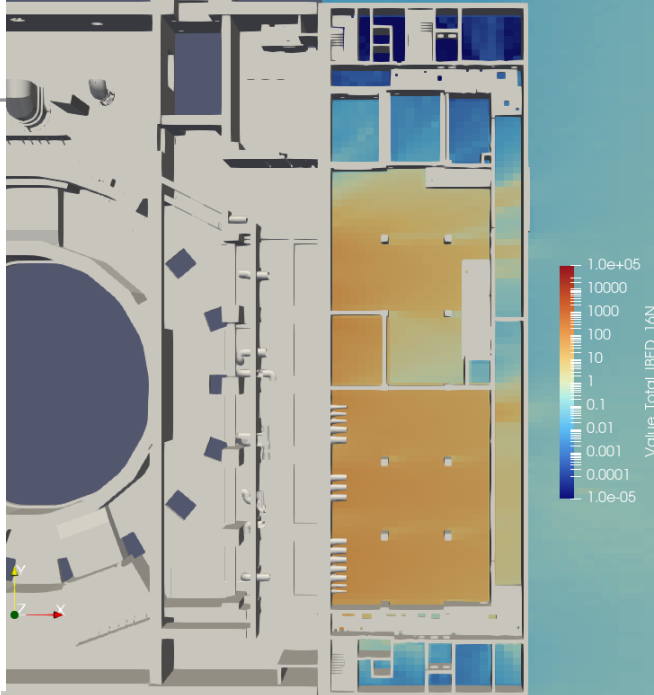
- Multiple energy line handling
- Energy and material dependent build up handling with e.g.: Geometrical Progression
- Cluster compatibility
- Input deck save and load
- To have a standard code for ^{16}N and ^{60}Co but still keep flexibility of the code
- Goal is to have the new version by the end of the year

The screenshot displays the Radiation Shielding GUI with three main panels:

- STL Files:** A list of STL files with their respective densities. A button "Add Custom STL Files" is at the bottom.
- File Inputs and Bounding Boxes:** Fields for Source CSV File (source_intensity.txt), Target CSV File (TKC_voxel_centers.txt), and Source/Target Bounding Boxes (X, Y, Z Min/Max). It also includes Air density (0.001293) and buttons for "Load Input Deck", "Save input deck", and "Save and Run".
- Energy Lines:** A table with columns for Enable, Energy (MeV), Relative Intensity, Dose Conversion Factor, MAC_air, B_inf_air, C_air, and material-specific coefficients for Lead and Heavy_Concrete.

Enable	Energy (MeV)	Relative Intensity	Dose Conversion Factor	MAC _{air}	B _{inf} _{air}	C _{air}	Lead			Heavy_Concrete			Norm	
							Mass Att. Coeff	B _{inf}	C	Mass Att. Coeff	B _{inf}	C		
<input checked="" type="checkbox"/>	0.7872	4.10247E-0E	0.0168	0.070740	1.0	0.1	0.0887	1.2	0.7	0.06936	1.2	0.7	0.07227	1
<input checked="" type="checkbox"/>	0.8677	2.87173E-0E	0.01980	0.063580	1.05	0.12	0.07102	1.1	0.65	0.06112	1.1	0.65	0.06495	1
<input checked="" type="checkbox"/>	0.98693	4.64947E-0E	0.01980	0.063580	1.1	0.15	0.05876	1.3	0.75	0.06112	1.3	0.75	0.06495	1
<input checked="" type="checkbox"/>	1.0675	4.10247E-0E	0.02510	0.056870	1.15	0.18	0.05222	1.2	0.7	0.05404	1.2	0.7	0.0527	1
<input checked="" type="checkbox"/>	1.7549	0.00165466	0.02990	0.044470	1.2	0.2	0.04606	1.1	0.65	0.04296	1.1	0.65	0.04557	1
<input checked="" type="checkbox"/>	1.9547	0.00051964	0.03420	0.044470	1.25	0.25	0.04472	1.3	0.75	0.04296	1.3	0.75	0.04557	1
<input checked="" type="checkbox"/>	2.7415	0.01121342	0.04010	0.035810	1.3	0.3	0.04234	1.2	0.7	0.03676	1.2	0.7	0.03701	1
<input checked="" type="checkbox"/>	2.8222	0.00177773	0.04410	0.035810	1.35	0.35	0.04234	1.1	0.65	0.03676	1.1	0.65	0.03701	1
<input checked="" type="checkbox"/>	6.12863	0.91621873	0.06740	0.022250	1.4	0.4	0.04391	1.3	0.75	0.03116	1.3	0.75	0.02432	1
<input checked="" type="checkbox"/>	6.9155	0.00051964	0.07660	0.022250	1.45	0.45	0.04675	1.2	0.7	0.03116	1.2	0.7	0.02432	1
<input checked="" type="checkbox"/>	7.11515	0.06700704	0.07660	0.022250	1.5	0.5	0.04675	1.1	0.65	0.03116	1.1	0.65	0.02432	1
<input checked="" type="checkbox"/>	8.8693	0.00103929	0.08770	0.020450	1.55	0.55	0.04972	1.3	0.75	0.03138	1.3	0.75	0.02278	1

Radmap2020, IBED ^{16}N dose rate,
Z=1308 cm



PRELIMINARY!

Performance

12 Energy lines of ^{16}N

1718 source points at UPC

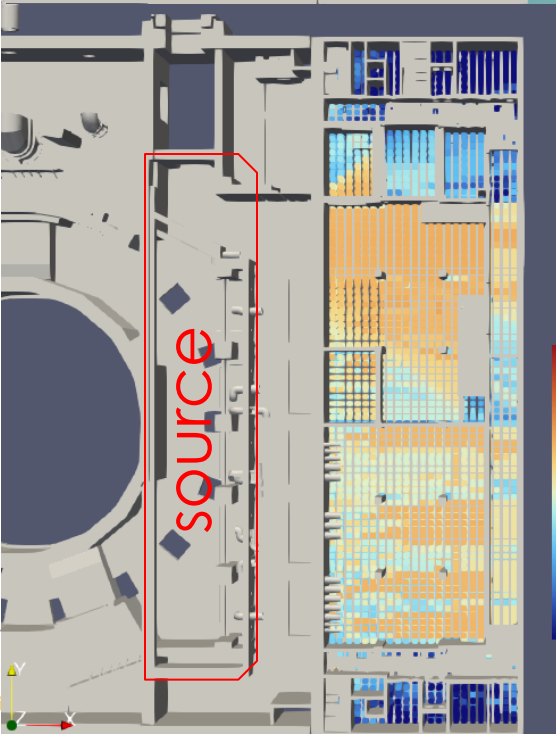
15300 target points:

~43 hours with 8 cores

Using geometries:

- TKC NC structures,
- TKC HC structures,
- TKC Steel structures
- Backfilling+cable trays
- TCWS pipes
- TCWS water
- TCWS lead
- TCWS Novashield
- TCWS concrete

Point kernel
based, no build
up, Z=1308 cm



Pros and cons

- Pros:
 - Independent method from MCNP
 - 3D CAD geometry, no difficult geometry preparation
 - No special expertise is needed to use the code
 - Significantly less computational cost is foreseen
 - Quick results, for design or for comparative studies
 - May be used for error estimates
 - Point source approximation
- Cons:
 - Limited to gamma
 - Some phenomena can't be modelled (skyshine, backscattering)
 - Point source approximation (more accurate for large distances)
 - Build-up approximation

Collaborators are welcomed!

