

# FLUKA Simulations of Radiation Field in Second Accelerator Tunnel

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# Contents



The purpose of this study is to calculate produced radiation dose rates and define an appropriate radiation shielding in order to ensure that no radiation exits the accelerator area, i.e. dose level below  $3 \mu\text{Sv/h}$  (controlled area limit)

- ❖ Using the FLUKA code to model the radiation field is necessary
  - ✓ Define the geometry
  - ✓ Define FLUKA cards
- ❖ Using the FLUKA code were obtained the following results
  - ✓ The equivalent dose distribution in the tunnel
  - ✓ Dose rate distribution for different shielding configuration



# FLUKA Applications



- FLUKA is a Monte Carlo code developed for high energy physics. The code is written in Fortran and it is used for calculations of particle transport and interactions with matter.

**FLUKA can be applied:**

- Accelerator design
- Particle design
- Shielding design
- Cosmic ray physics
- Space radiation etc.



# Define FLUKA cards



## Some FLUKA card used for the simulations:

- LOW-MAT:** Correspondence between FLUKA materials and low energy neutron cross sections:

<b>LOW-MAT</b>	Mat: CHROMIUM ▼	LowMat: Cr. Natural Chromium, 296K ▼
<b>LOW-MAT</b>	Mat: IRON ▼	LowMat: Fe. Natural Iron, 296K ▼
<b>LOW-MAT</b>	Mat: NICKEL ▼	LowMat: Ni. Natural Nickel, 296K ▼
<b>LOW-MAT</b>	Mat: ALUMINUM ▼	LowMat: 27Al. Aluminium 27, 296K ▼

- PHOTONUC :** Activate photonuclear interaction

<b>PHOTONUC</b> E>0.7GeV off ▼	Type: ▼ Δ resonance off ▼ Mat: BLCKHOLE ▼	Quasi D off ▼ to Mat: @LASTMAT ▼	All E: On ▼ Giant Dipole off ▼ Step: ▼
<b>PHOTONUC</b> E>0.7GeV off ▼	Type: ELECTNUC ▼ Δ resonance off ▼ Mat: VACUUM ▼	Quasi D off ▼ to Mat: STAINLES ▼	All E: On ▼ Giant Dipole off ▼ Step: ▼

- LOW-NEUT:** Activates low-energy neutron transport

<b>LOW-NEUT</b>	n-groups: 260 ▼ Print: ▼	γ-groups: 42 ▼ Point Wise: Enable ▼	Emax: 0.02 ▼ (n,f) Multiplicity: default ▼
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- EMFCUT:** Energy threshold production: 20 keV for photon and 20 keV for electron and positron

Energy 20 keV <b>EMFCUT</b> Fudgem: 0	Type: PROD-CUT ▼ e-e+ Threshold: Kinetic ▼ Mat: BLCKHOLE ▼	e-e+ Ekin: 2e-5 to Mat: @LASTMAT ▼	γ: 2E-05 Step: 1
Energy 20 keV <b>EMFCUT</b>	Type: transport ▼ e-e+ Threshold: Kinetic ▼ Reg: PPOUT ▼	e-e+ Ekin: 2e-5 to Reg: @LASTREG ▼	γ: 2E-05 Step: 1

# Define the Geometry

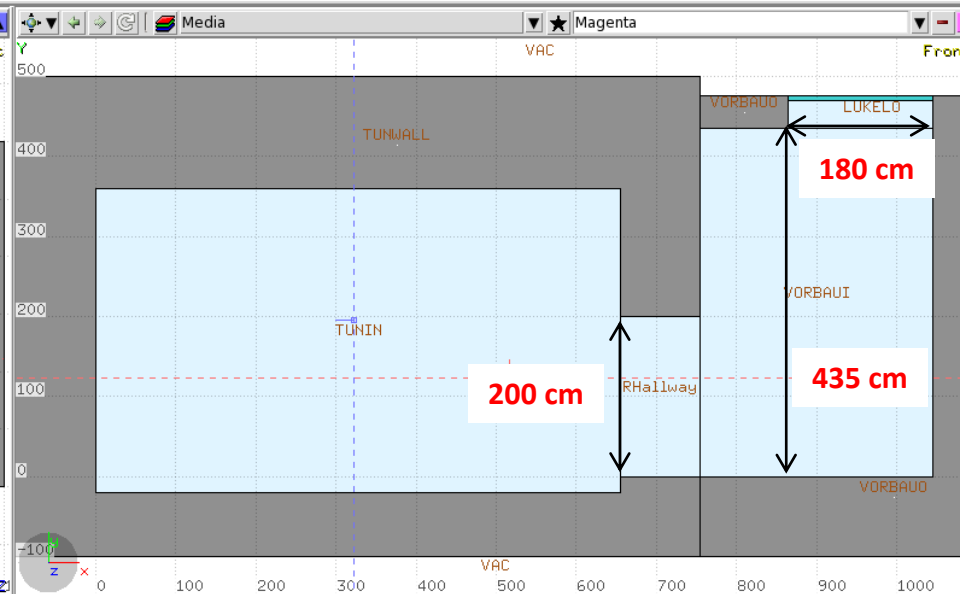
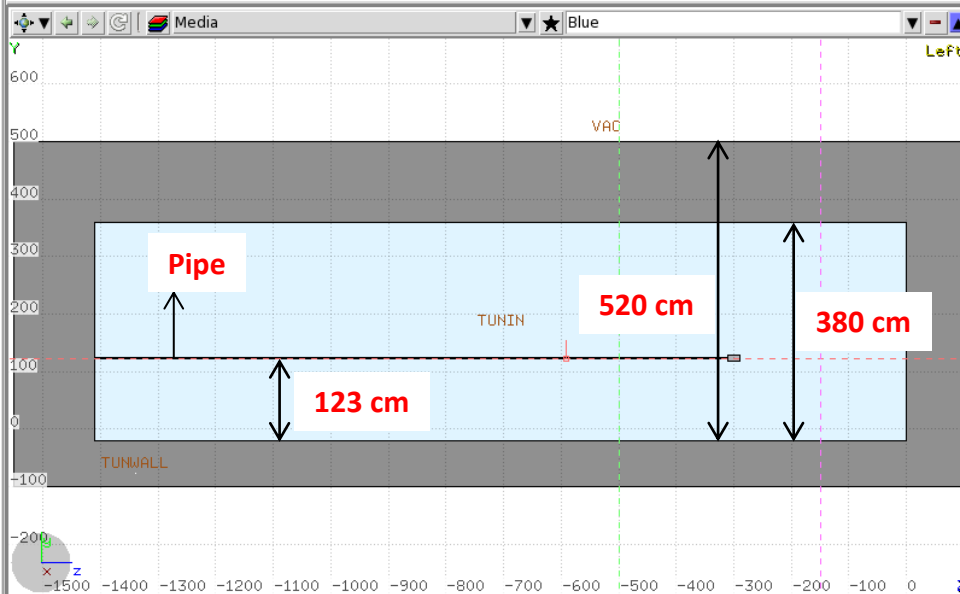
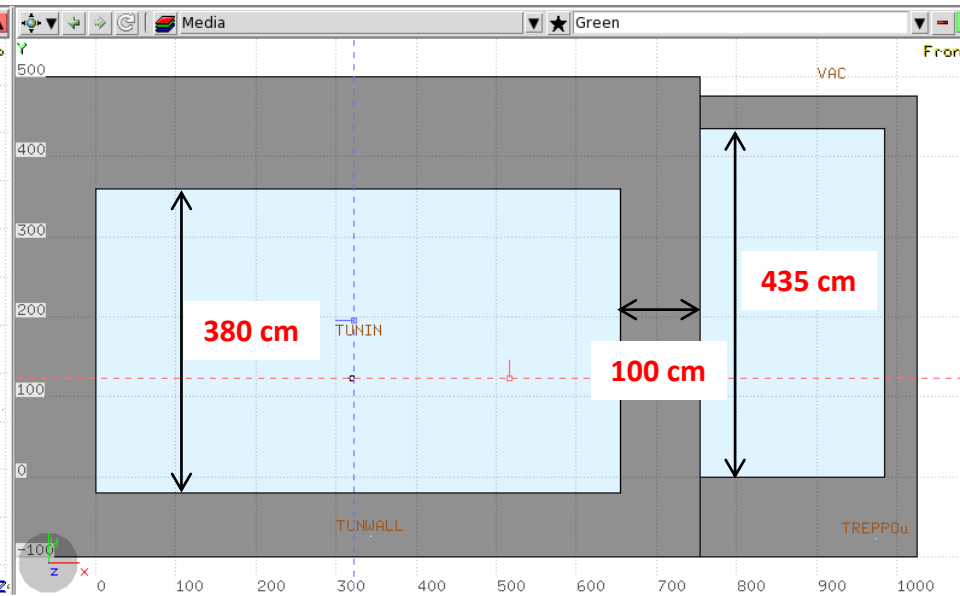
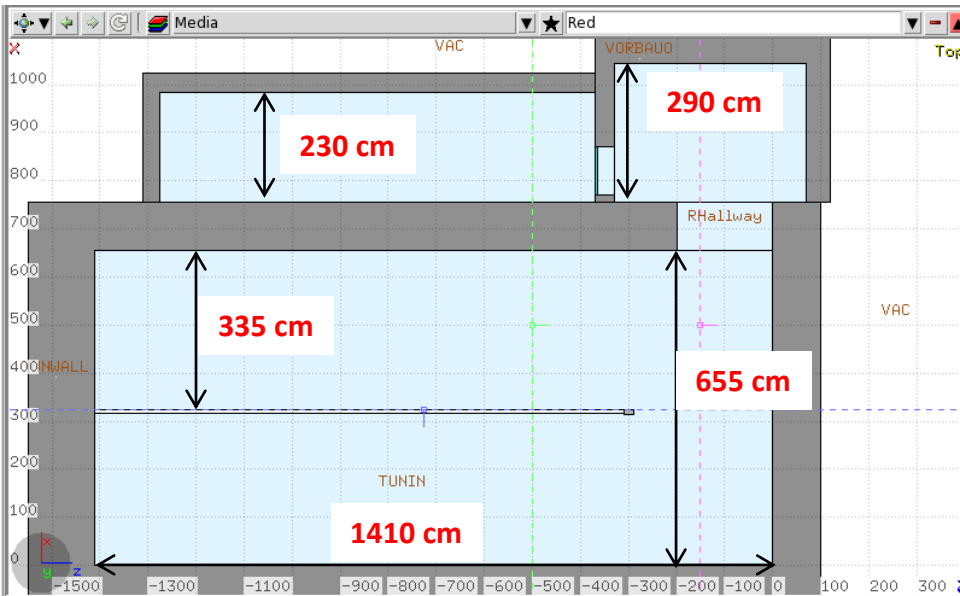


Diagram of the tunnel hall in the XZ and YX planes around the pipe.

# Define the Geometry

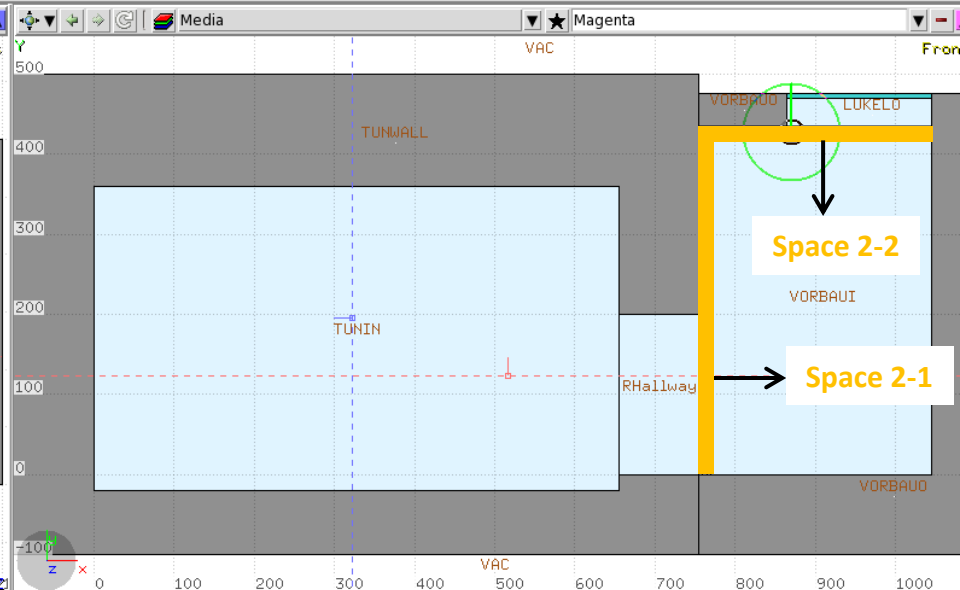
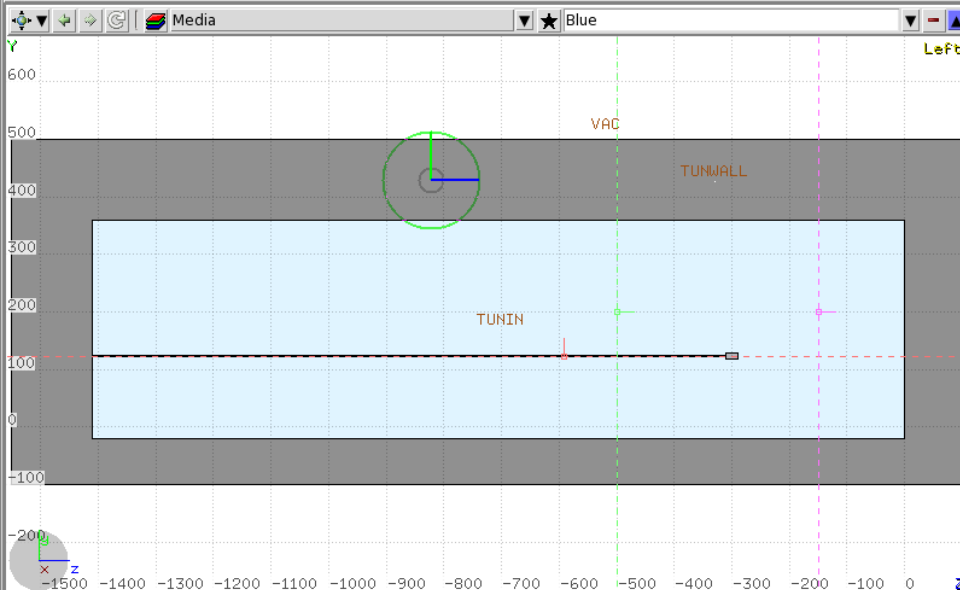
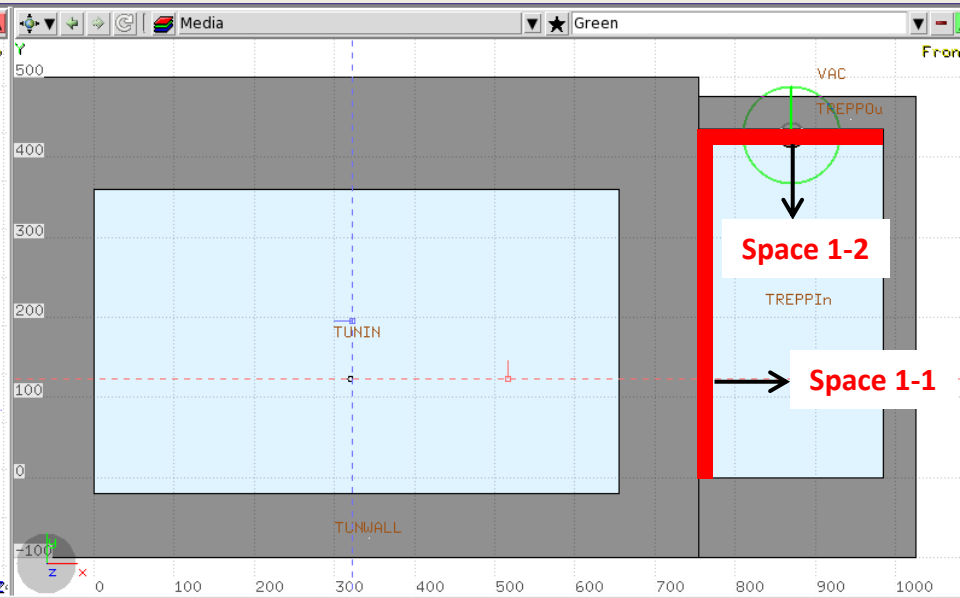
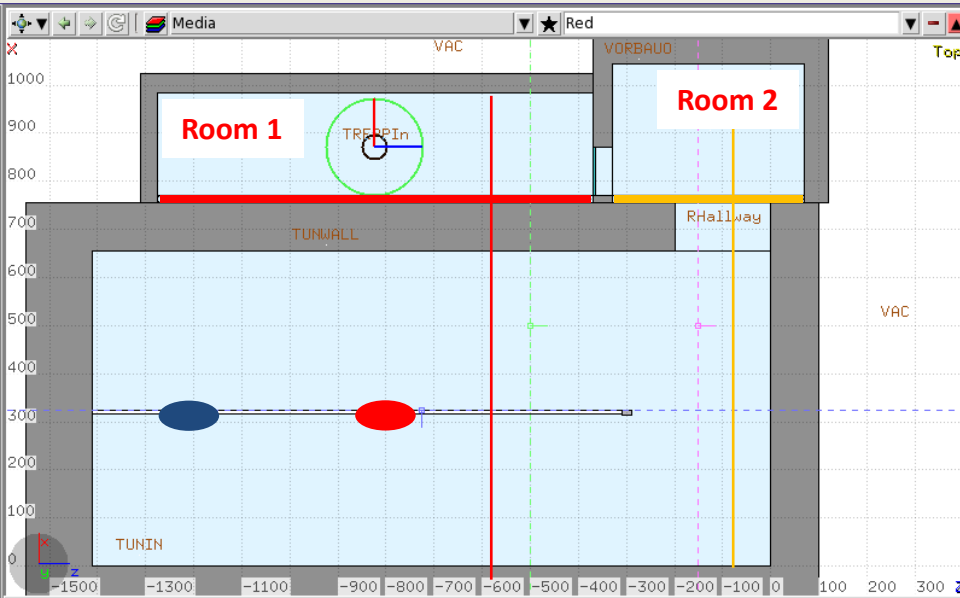
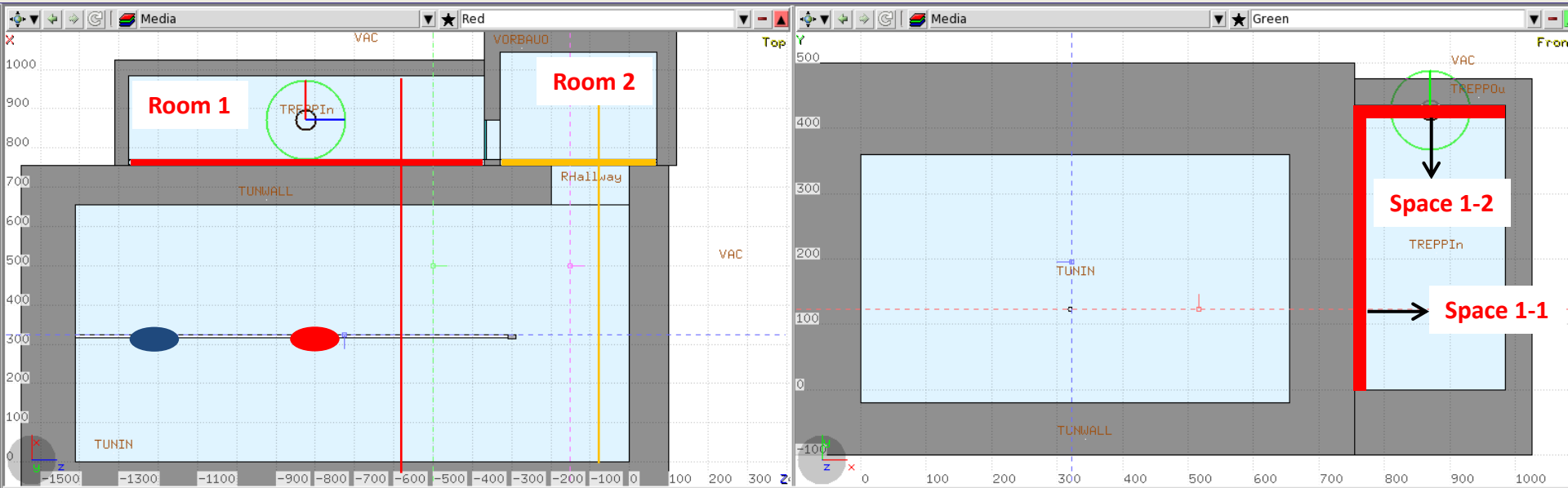


Diagram of the tunnel hall in the XZ and YX planes around the pipe.

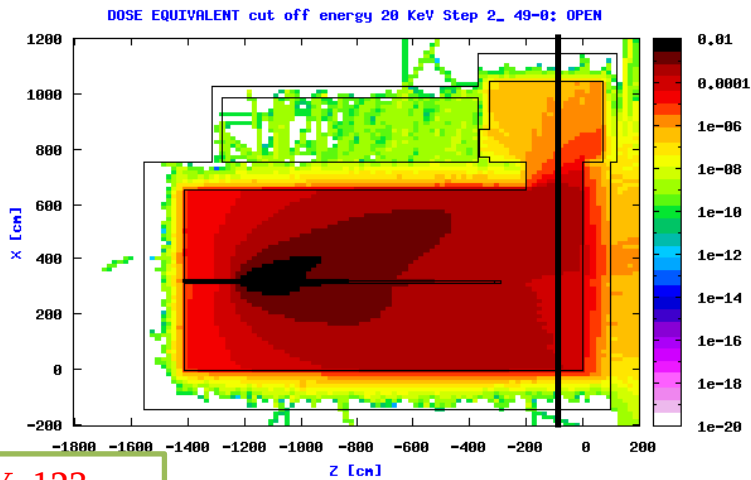
# Define the Geometry



**Materials that were used in simulations:**

<p><b>MATERIAL</b></p> <p><b>COMPOUND</b></p> <p>f1: 0.01 f3: 0.529107 f5: 0.002 f7: 0.337021 f9: 0.044 f11:</p>	<p>Name: <b>PORTLAND</b></p> <p>Am:</p> <p>Name: PORTLAND ▾</p> <p>M1: HYDROGEN ▾</p> <p>M3: OXYGEN ▾</p> <p>M5: MAGNESIU ▾</p> <p>M7: SILICON ▾</p> <p>M9: CALCIUM ▾</p> <p>M11: ▾</p>	<p>#</p> <p>A:</p> <p>Mix: Mass ▾</p> <p>f2: 0.001 f4: 0.016 f6: 0.033872 f8: 0.013 f10: 0.014 f12:</p>	<p>ρ: 2.3</p> <p>dE/dx: ▾</p> <p>Elements: 10.12 ▾</p> <p>M2: CARBON ▾</p> <p>M4: SODIUM ▾</p> <p>M6: ALUMINIUM ▾</p> <p>M8: POTASSIU ▾</p> <p>M10: IRON ▾</p> <p>M12: ▾</p>
<p><b>MATERIAL</b></p> <p><b>COMPOUND</b></p> <p>f1: 18.0 f3: 8.0</p>	<p>Name: <b>STAINLES</b></p> <p>Am:</p> <p>Name: STAINLES ▾</p> <p>M1: CHROMIUM ▾</p> <p>M3: NICKEL ▾</p>	<p>#</p> <p>A:</p> <p>Mix: Atom ▾</p> <p>f2: 74.0</p>	<p>ρ: 8.</p> <p>dE/dx: ▾</p> <p>Elements: 1.3 ▾</p> <p>M2: IRON ▾</p>

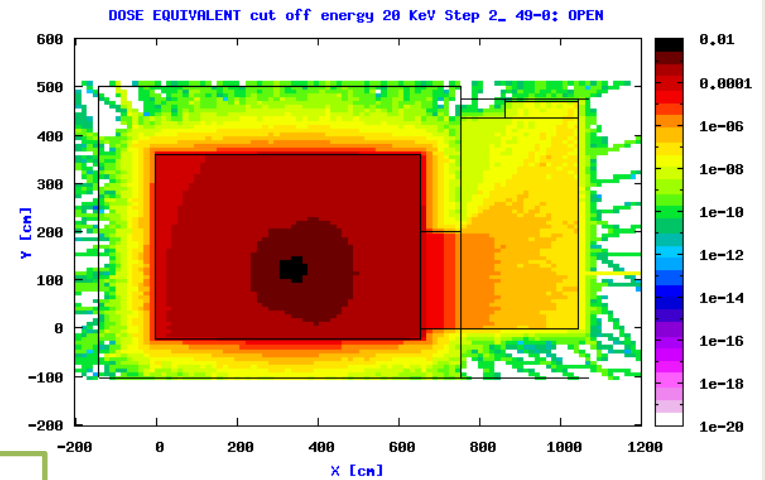
# Equivalent Dose Distribution [pSv per electron]



Step 1

Dose EQ: 312600

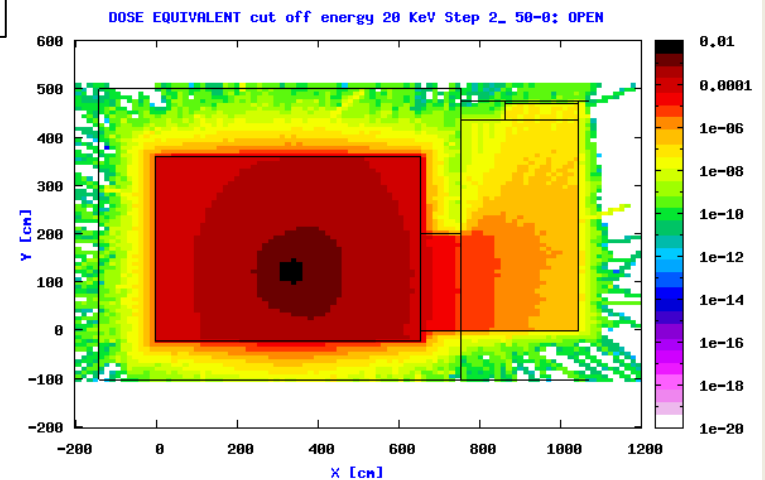
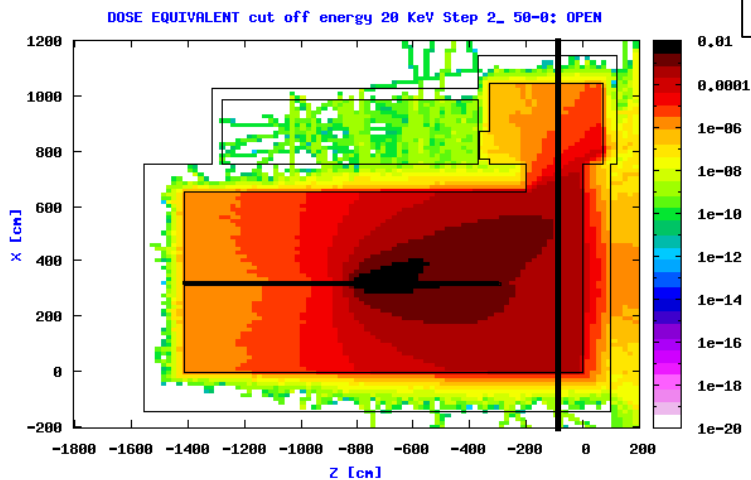
Z=-50cm



Step 2

Dose EQ: 403136 pSv

Z=-50cm

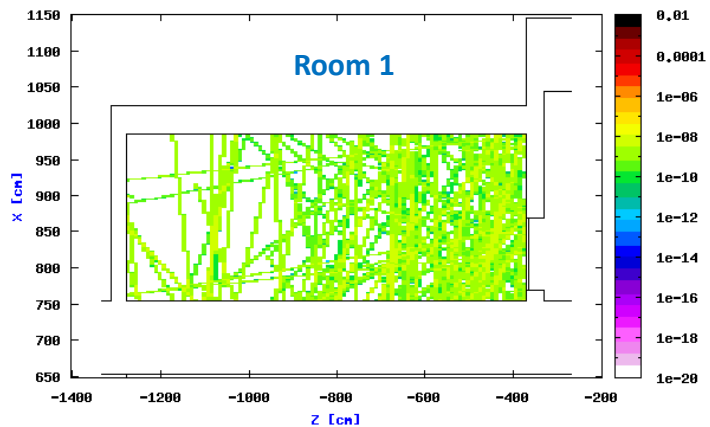


Y=123 cm

Equivalent dose distribution in XZ and YX plans in the tunnel hall (pSv per electron). a) interacts with the pipe in the position 1 b) interacts with the pipe in the position 2

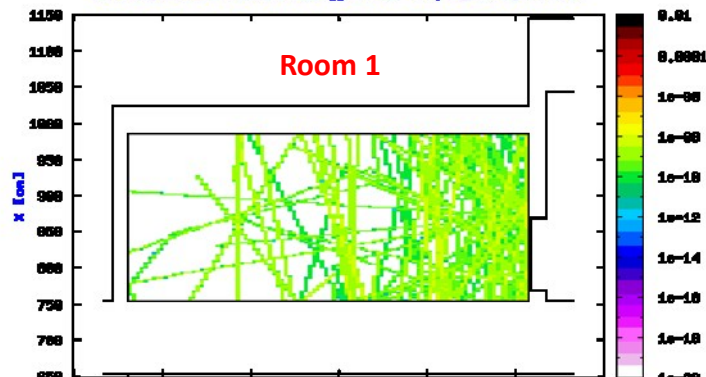


DOSE EQUIVALENT cut off energy 20 KeV Step 2\_ 49-0: Room 1

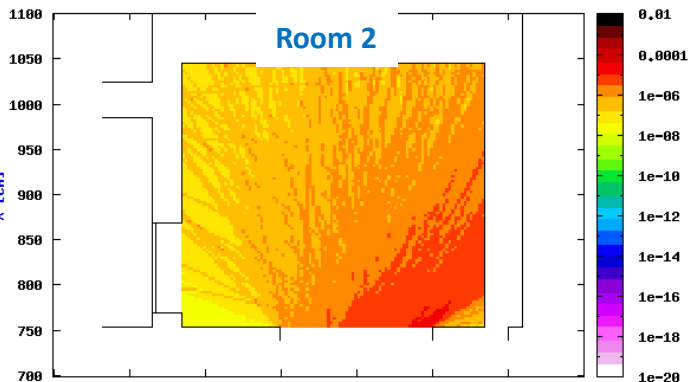


All: **0,093 pSv**  
 Elec: 2,59E-16  
 Phot: 0,0929  
 Neu : 1E-30

DOSE EQUIVALENT cut off energy 20 KeV Step 2\_ 50-0: Room 1

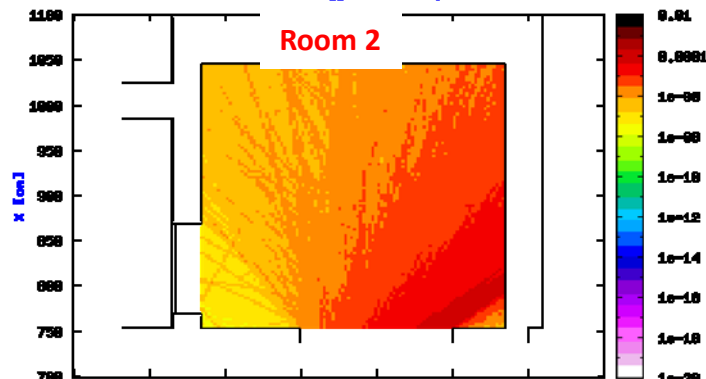


All: **0,05 pSv**  
 Elec: 1,31E-17  
 Phot: 0,05  
 Neu : 1E-30



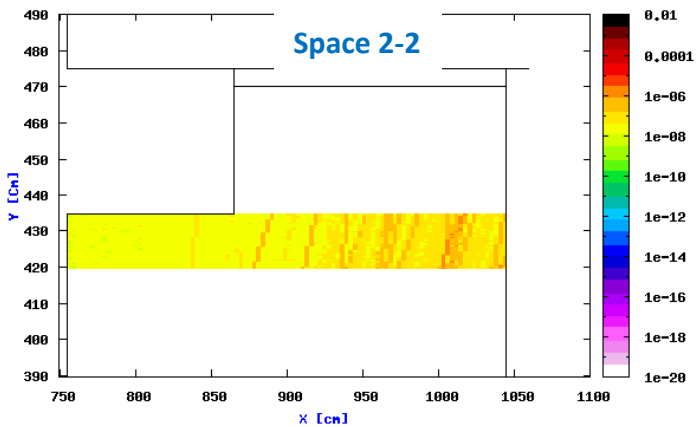
All: **61,54 pSv**  
 Elec: 47,32  
 Phot: 11,7  
 Neu : 0,43

DOSE EQUIVALENT cut off energy 20 KeV Step 2\_ 50-0: Room 2



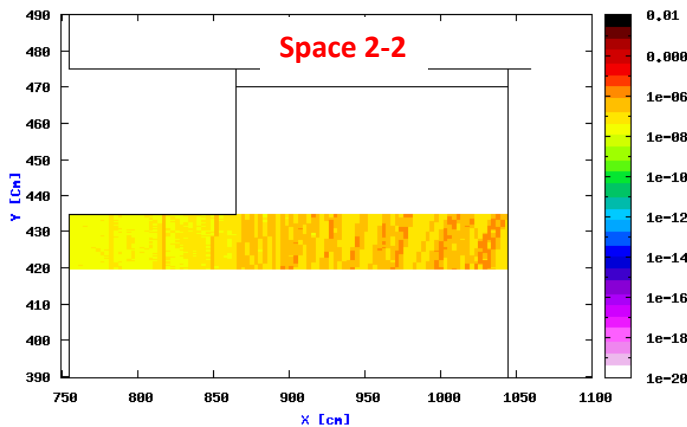
All: **255,1 pSv**  
 Elec: 221,5  
 Phot: 23,92  
 Neu : 1,01

DOSE EQUIVALENT cut off energy 20 KeV Step 2\_ 49-0: Person 11



All: **0,129 pSv**  
 Elec: 0,073  
 Phot: 0,055  
 Neu : 1E-30

DOSE EQUIVALENT cut off energy 20 KeV Step 2\_ 50-0: Person 11



All: **0,35 pSv**  
 Elec: 0,24  
 Phot: 0,096  
 Neu : 0,01

# Shielding Design

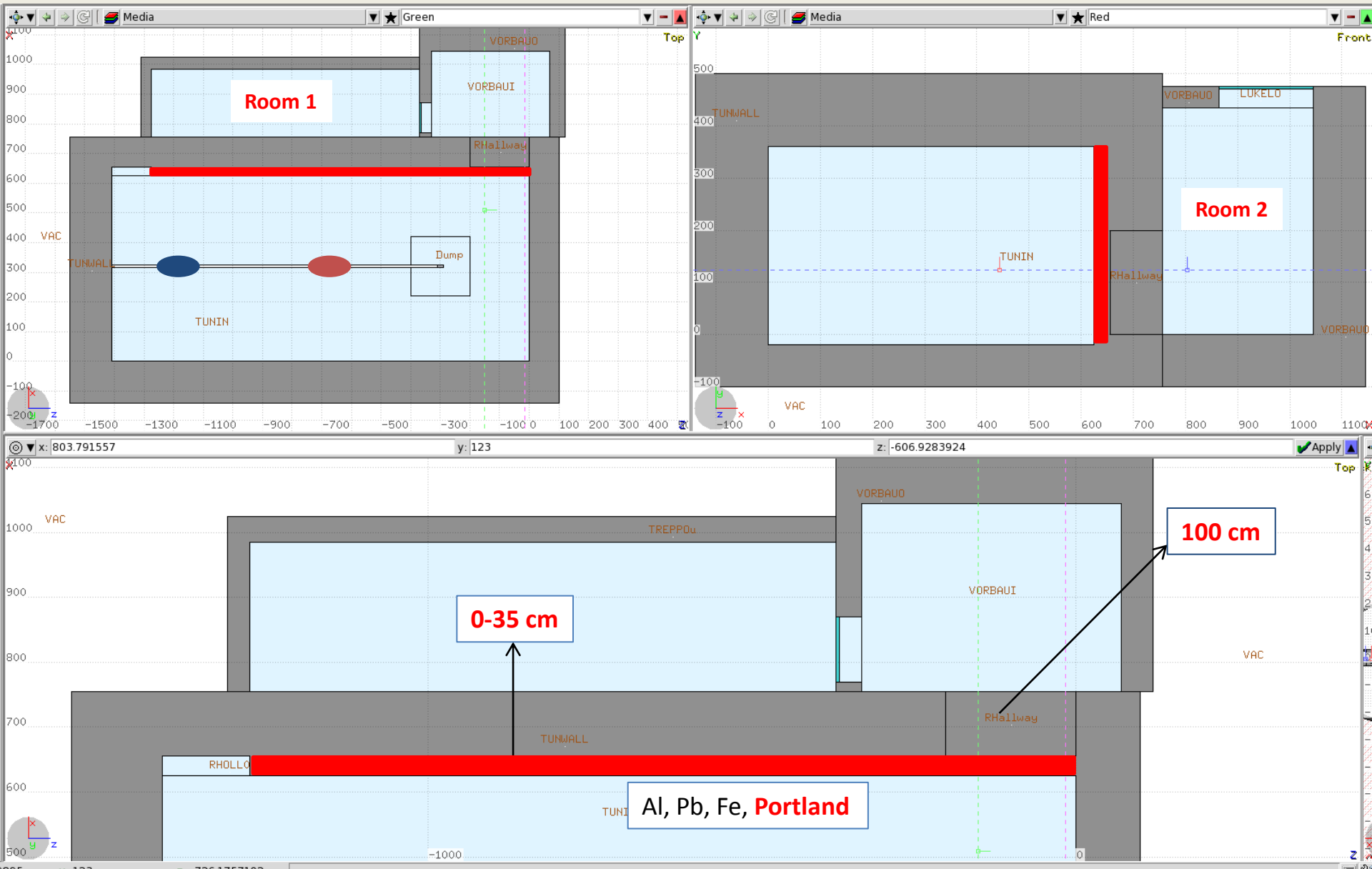
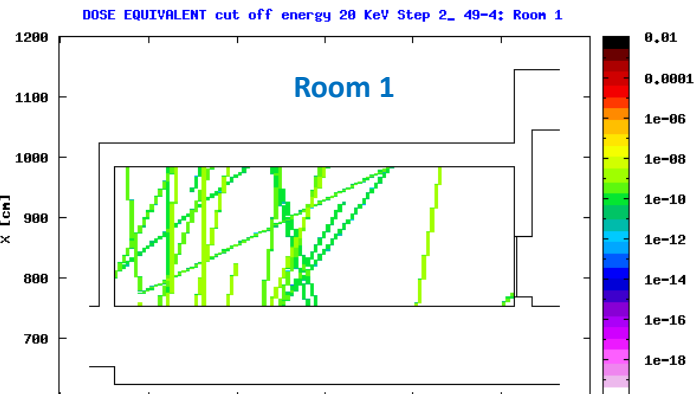


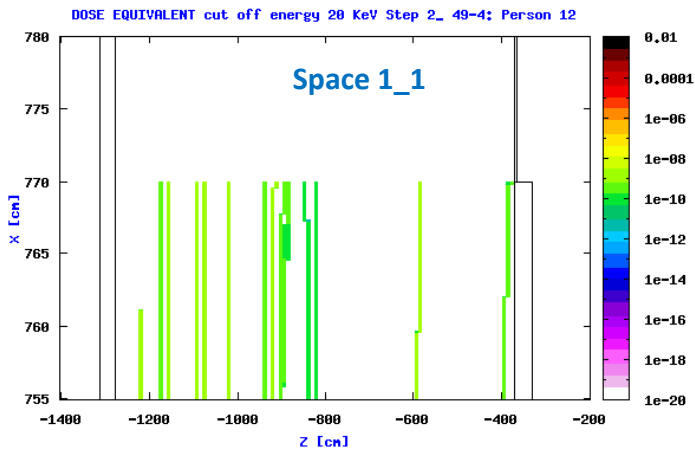
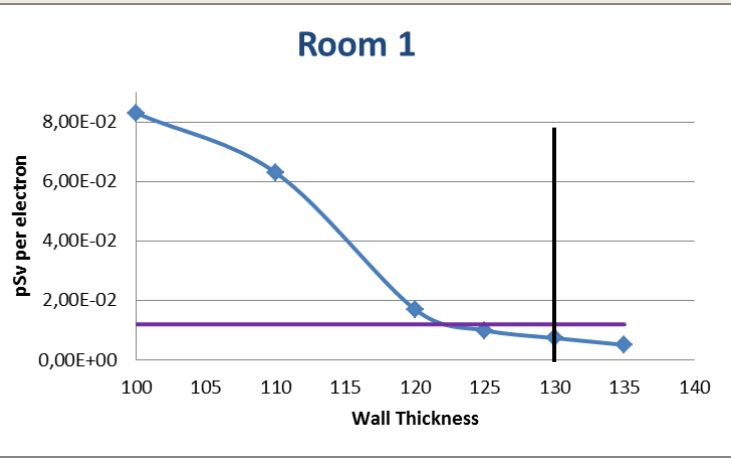
Diagram of the tunnel hall in the XZ and YX planes around the pipe.



30 cm

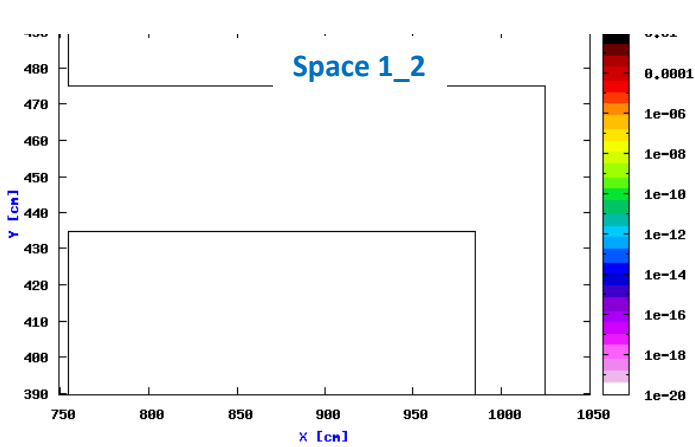
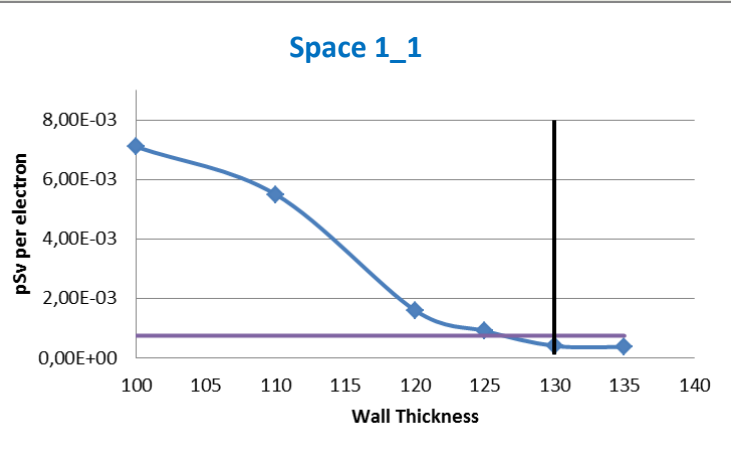
0,012 pSv

All: 0,0074 pSv  
 Elec: 9,8E-13  
 Phot: 0,0064  
 Neu : 1E-30



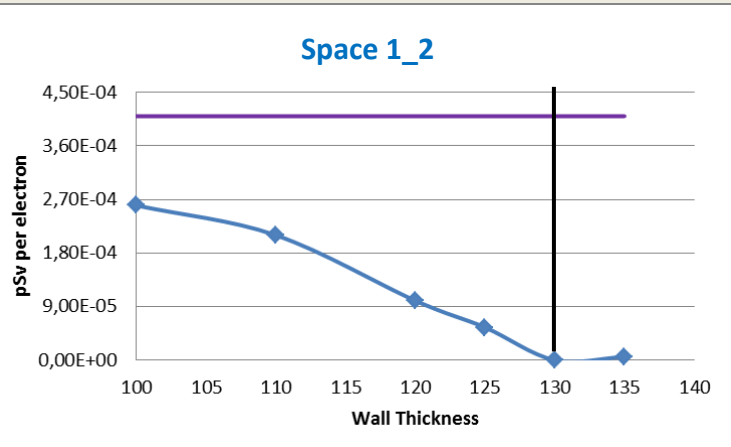
0,00075 pSv

All: 0,00041 pSv  
 Elec: 9,4E-13  
 Phot: 0,00046  
 Neu : 1E-30



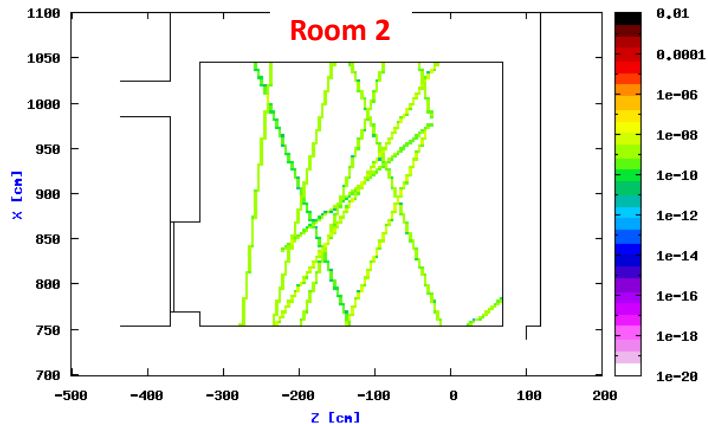
0,00041pSv

All: 1E-30  
 Elec: 1E-30  
 Phot: 1E-30  
 Neu : 1E-30



**30 cm**

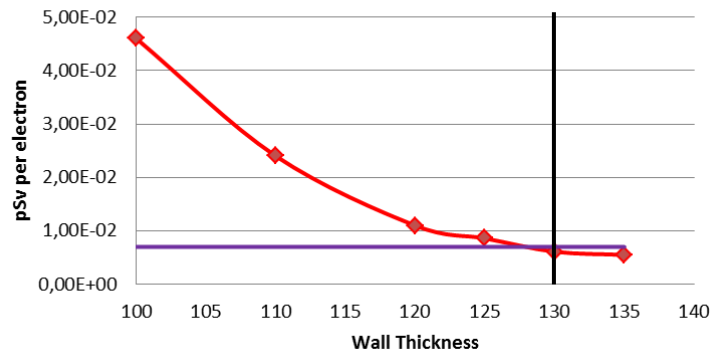
**Room 2**



**0,007 pSv**

All: **0,0061 pSv**  
 Elec: 1E-30  
 Phot: 0,0061  
 Neu : 1E-30

**Room 2**

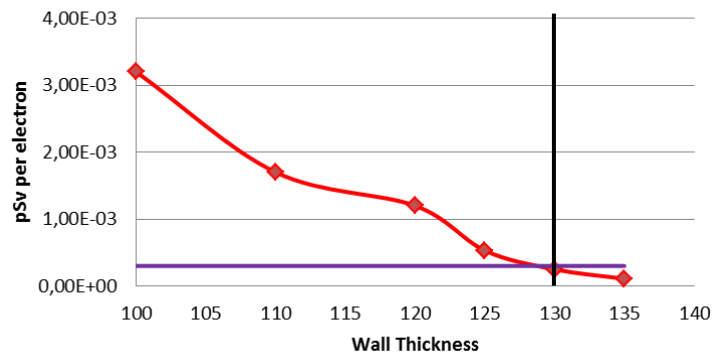


**Space 2-1**

**0,0003 pSv**

All: **0,00025 pSv**  
 Elec: 1E-30  
 Phot: 0,00025  
 Neu : 1E-30

**Space 2-1**

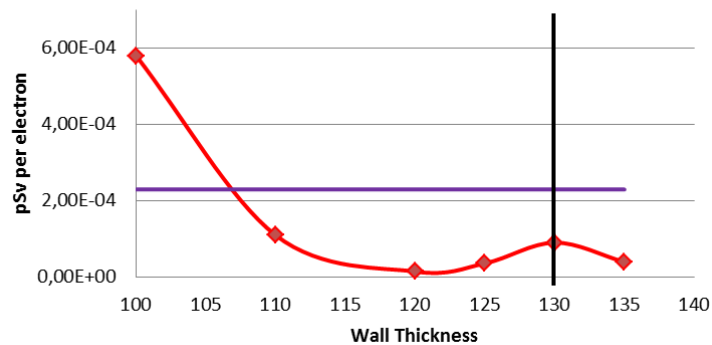


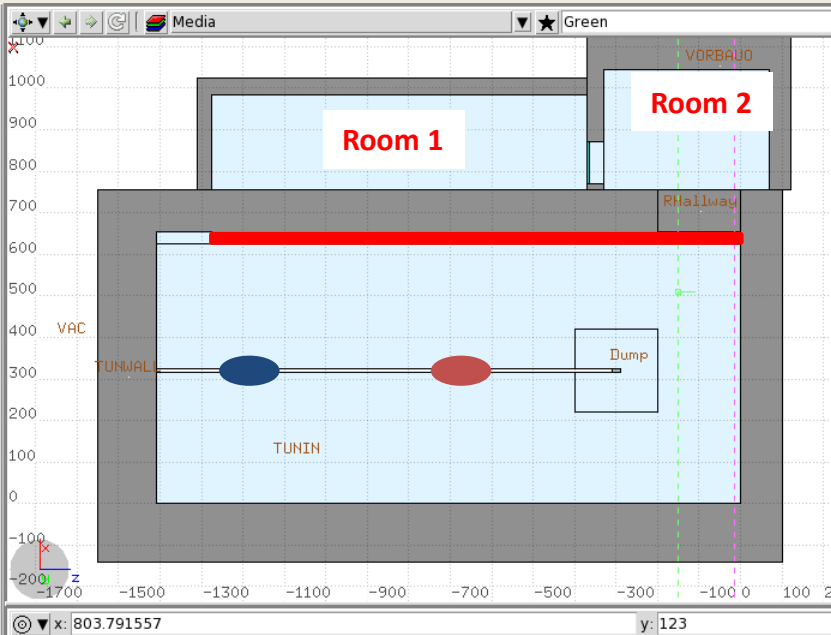
**Space 2-2**

**0,00023 pSv**

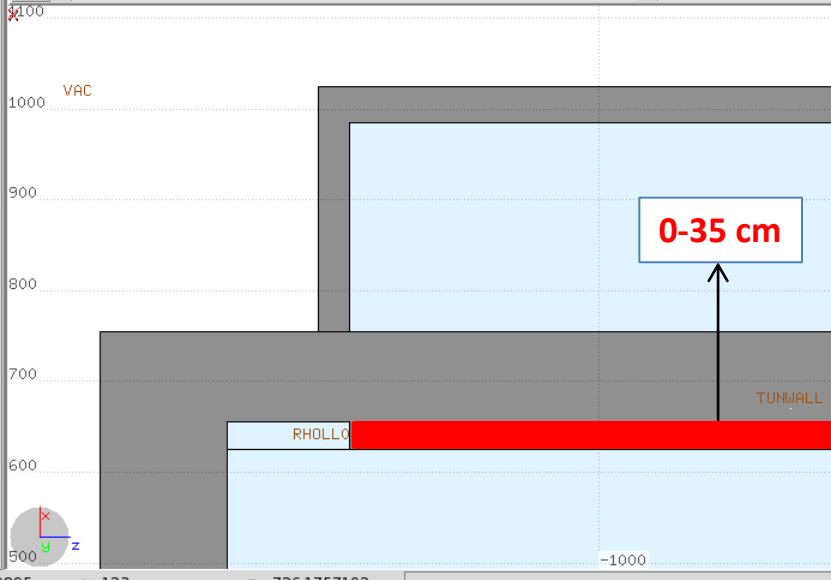
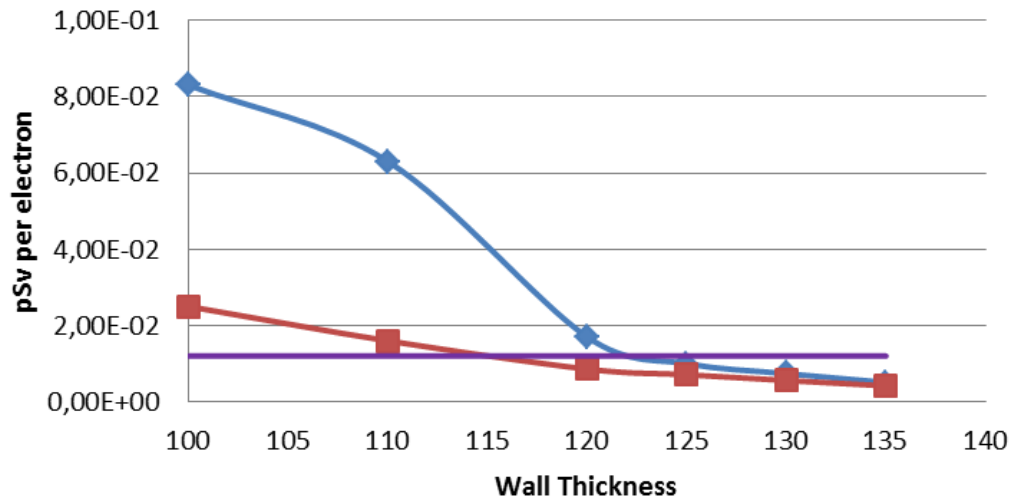
All: **9.61E-5 pSv**  
 Elec: 1E-30  
 Phot: 9.61E-5  
 Neu : 1E-30

**Space 2-2**

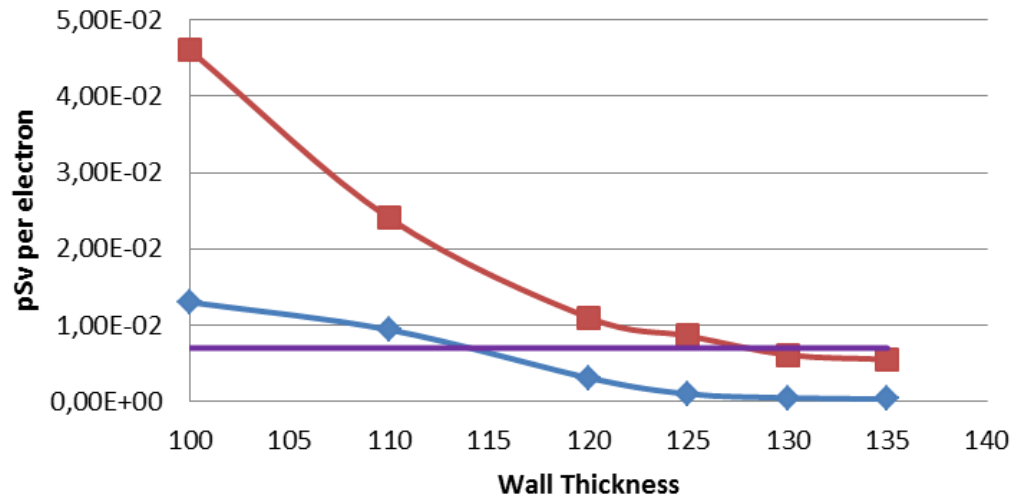




**Rooms 1: Left - Right**



**Rooms 2: Left - Right**



# Shielding Design

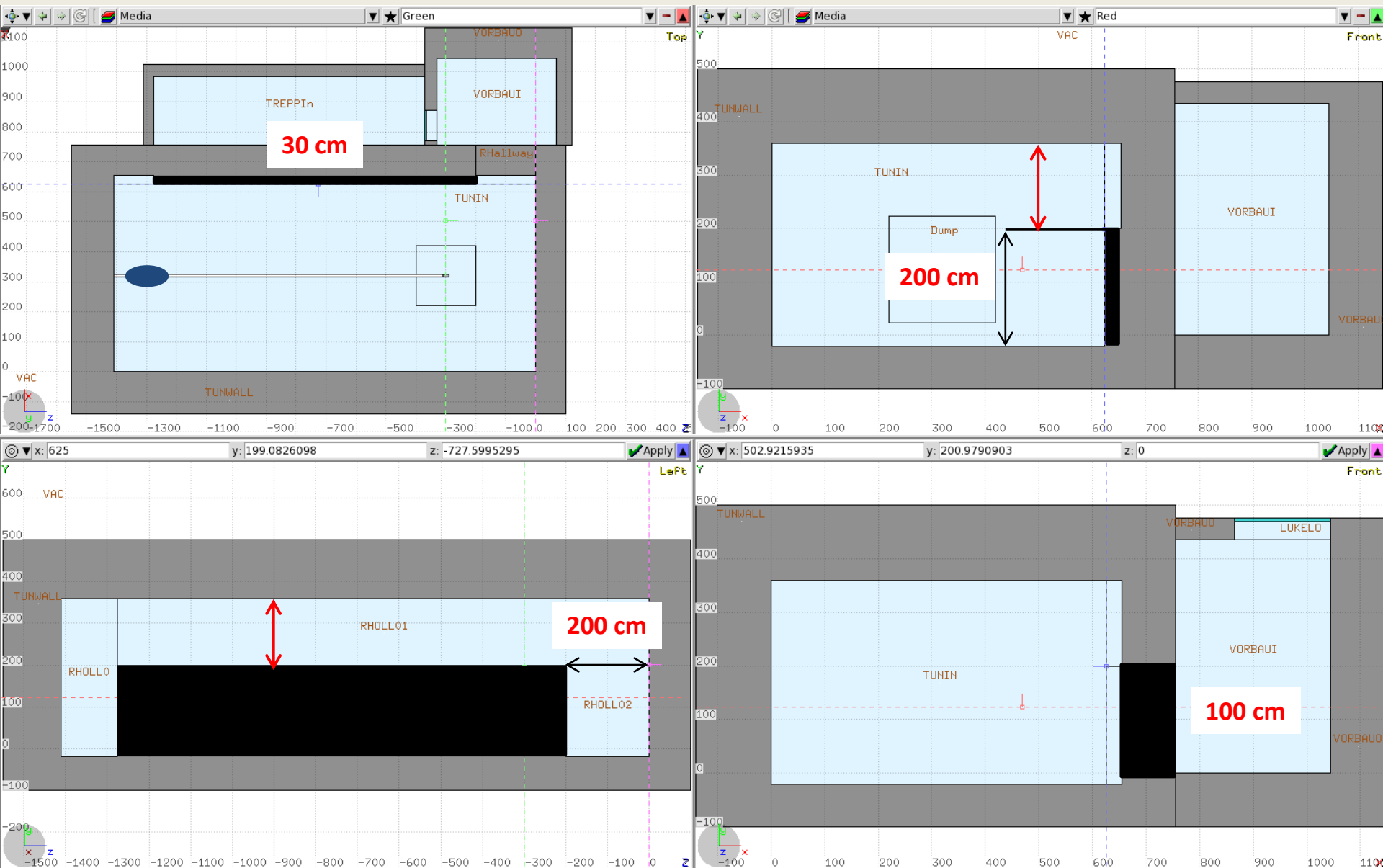
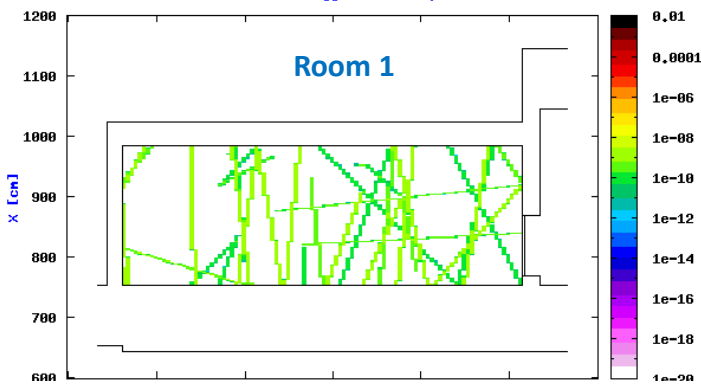


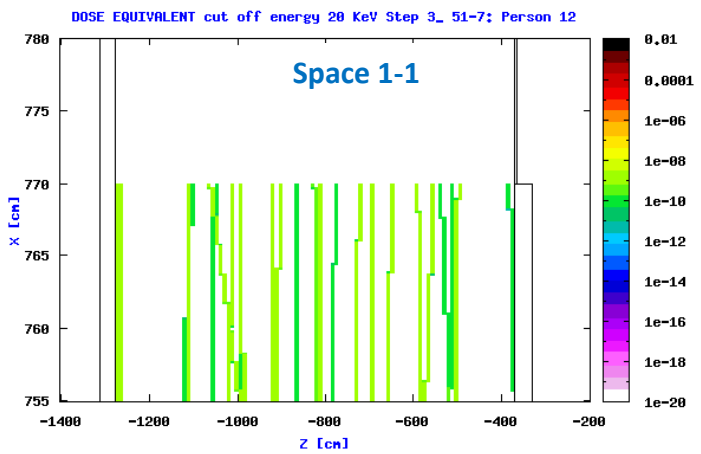
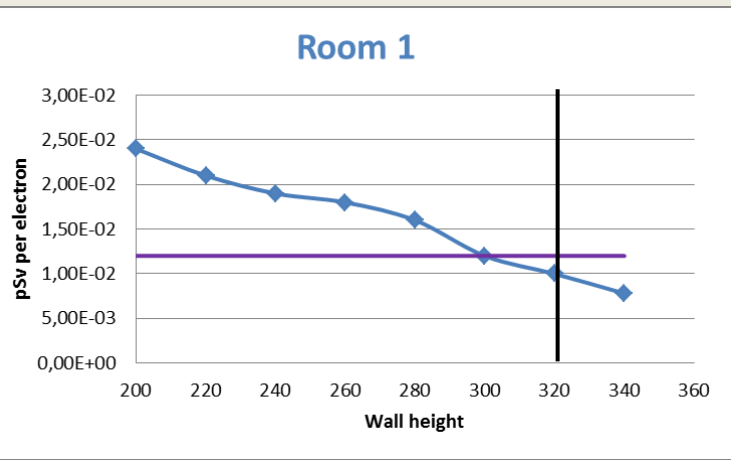
Diagram of the tunnel hall in the XZ and YX planes around the pipe.



**320 cm**

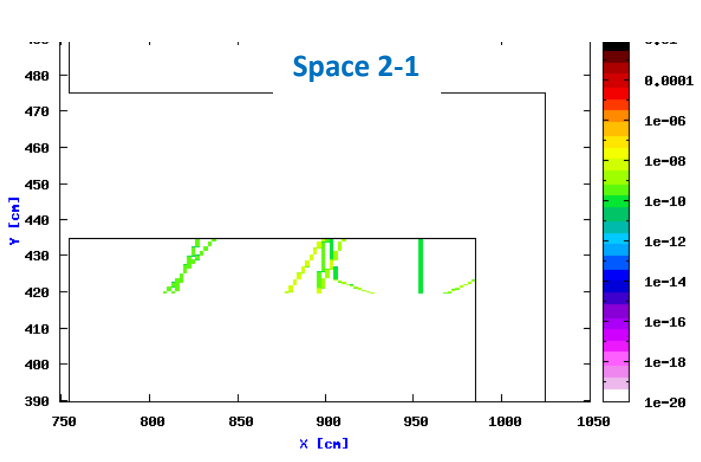
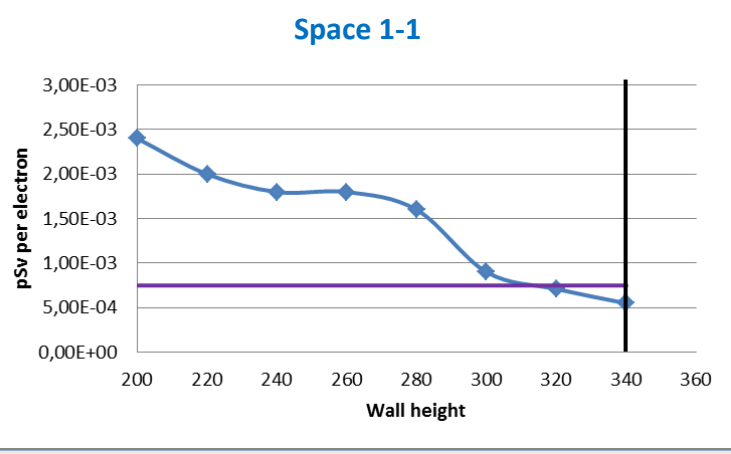
**0,012 pSv**

All: **0,01 pSv**  
 Elec: 1E-30  
 Phot: 0,01  
 Neu : 1E-30



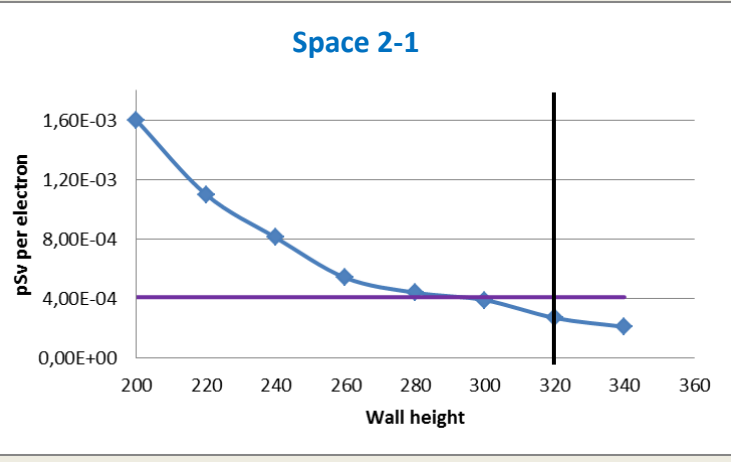
**0,00075 pSv**

All: **0,00071 pSv**  
 Elec: 1E-30  
 Phot: 0,00071  
 Neu : 1E-30



**0,00041 pSv**

All: **0,00027 pSv**  
 Elec: 1E-30  
 Phot: 0,00027  
 Neu : 1E-30



# Design of Shielding 1-0

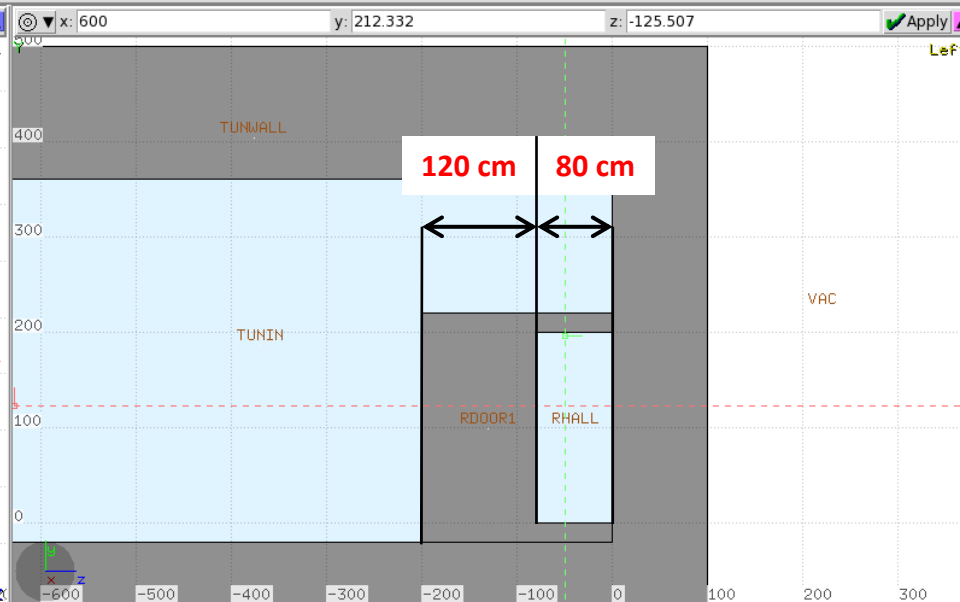
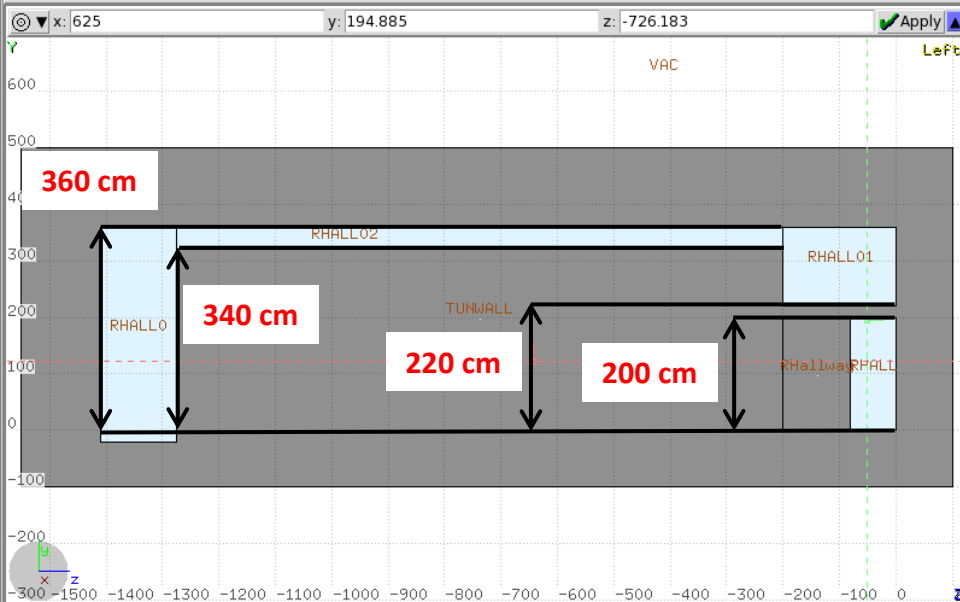
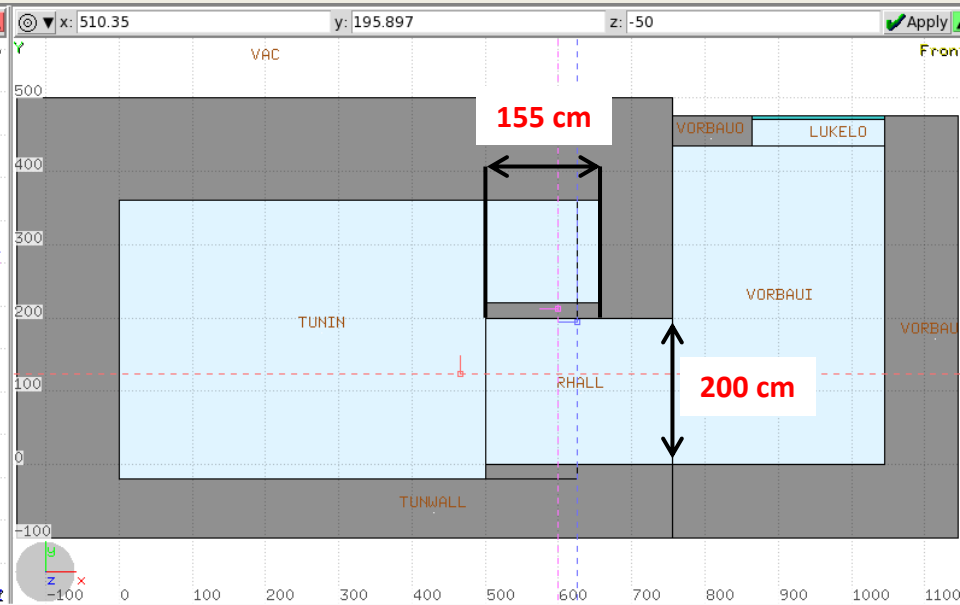
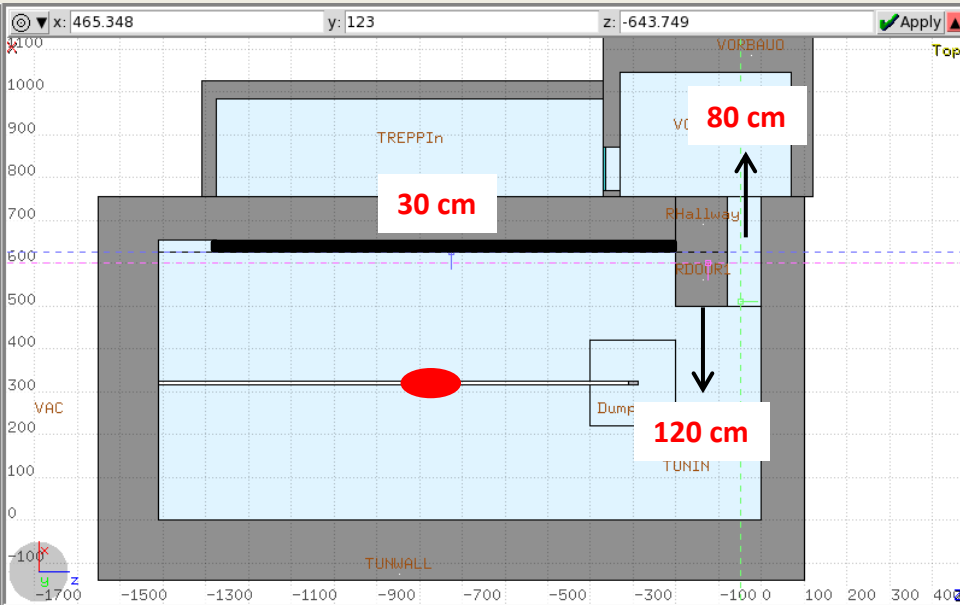
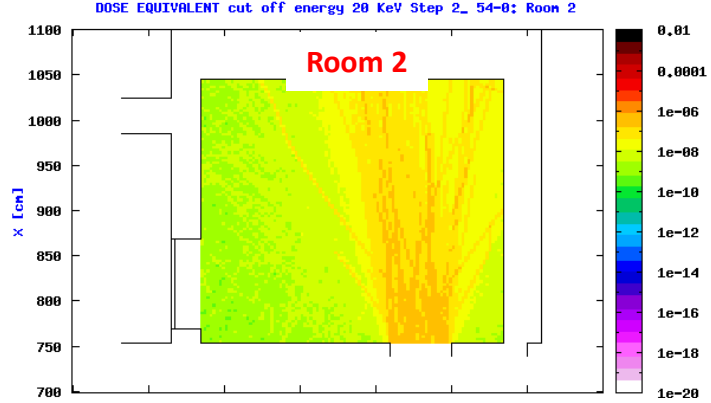
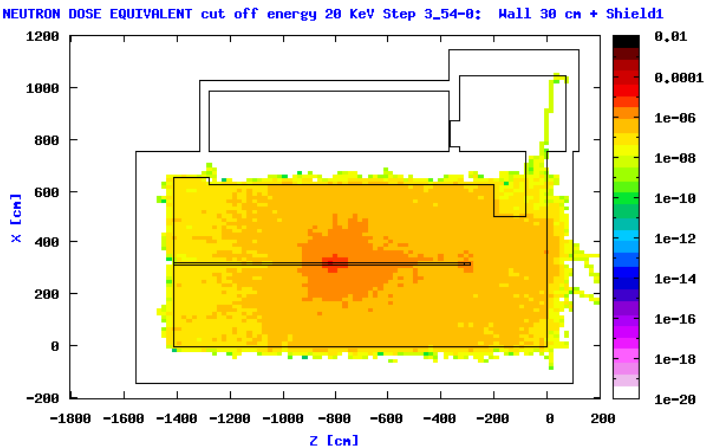
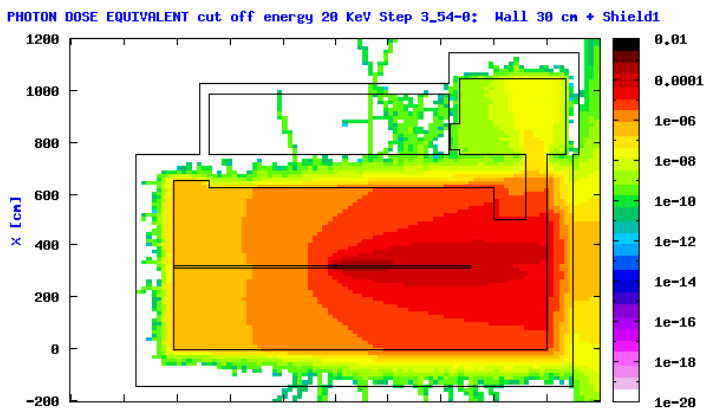
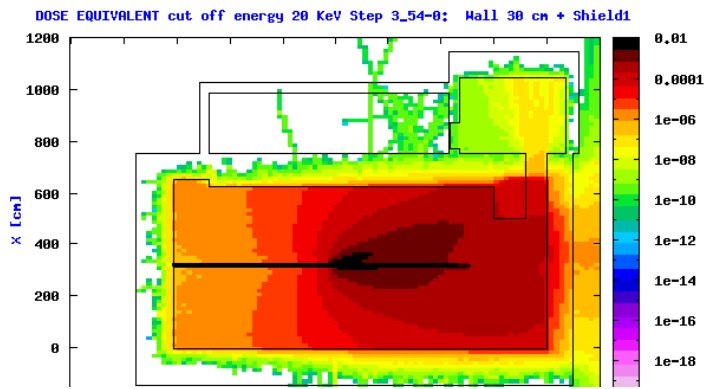
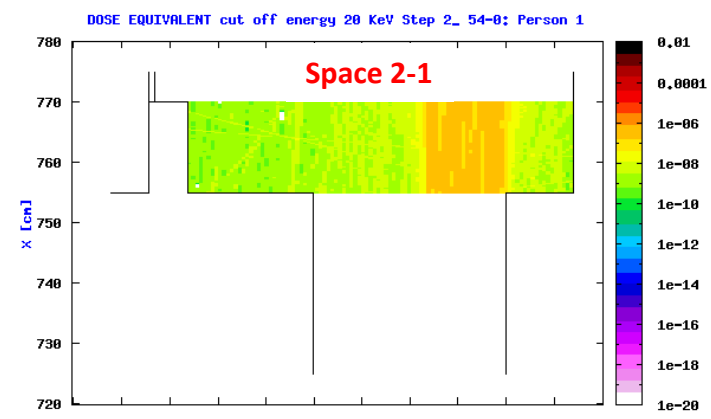


Diagram shielding 1-0 of the tunnel hall in the XZ and YX planes around the pipe.

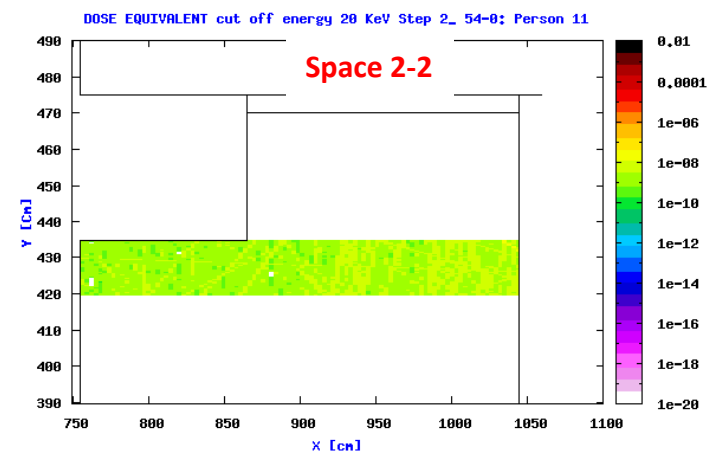




**0,007**  
 All: **2,238**  
 Elec: 0,95  
 Phot: 1,13  
 Neu : 0,048



**0,0003**  
 All: **0,14**  
 Elec: 0,064  
 Phot: 0,068  
 Neu : 0,0022



**0,00023**  
 All: **0,0036**  
 Elec: 3,76E-17  
 Phot: 0,0036  
 Neu : 1E-30

# Design of Shielding 1-0 With Doors

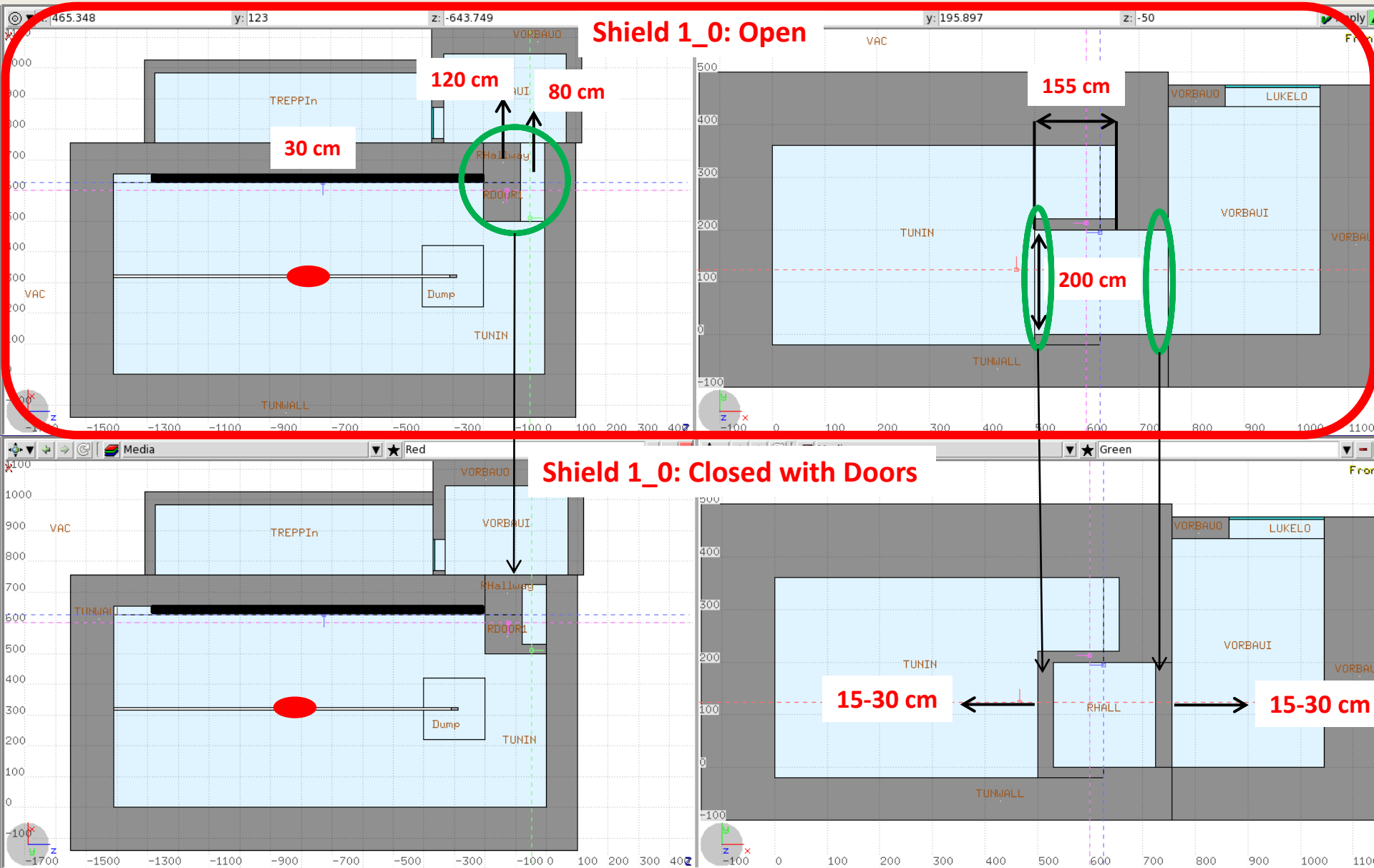
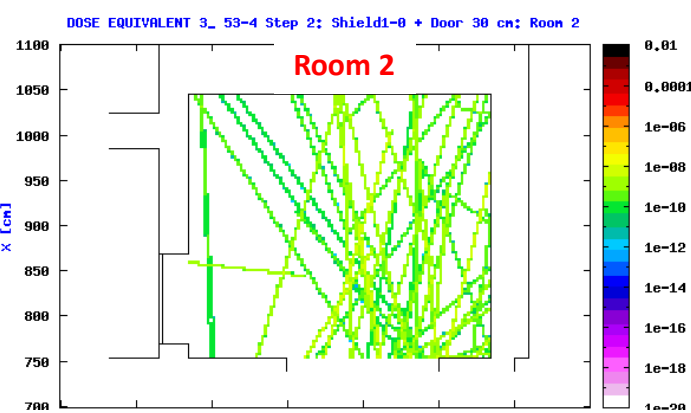


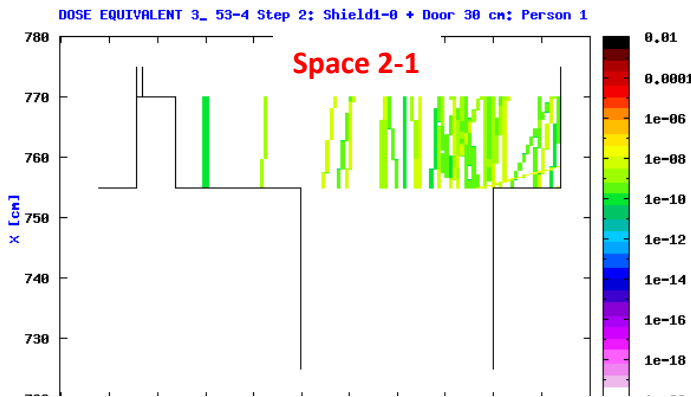
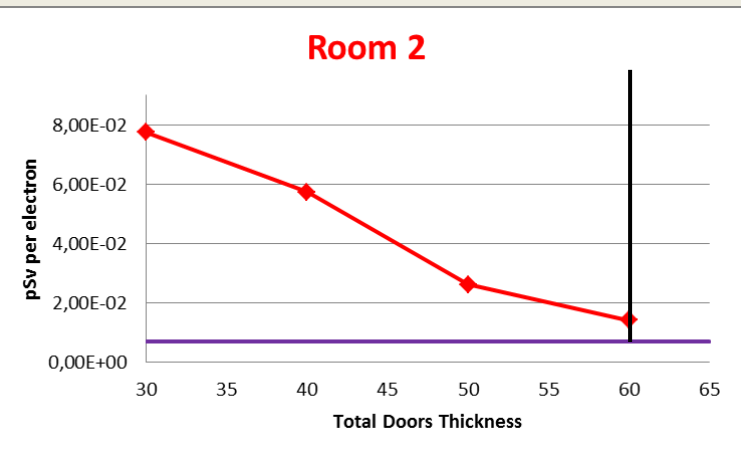
Diagram shielding 1-0 of the tunnel hall in the XZ and YX planes around the pipe.



**30 cm**

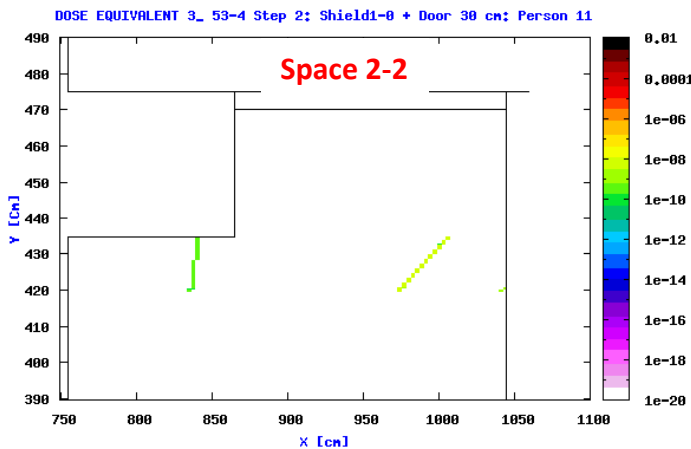
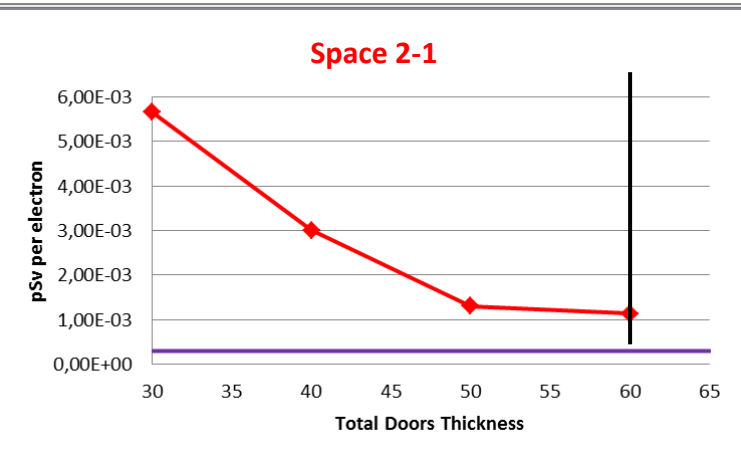
**0,007 pSv**

All: **0,0141**  
 Elec: 3,68E-18  
 Phot: 0,0141  
 Neu : 1E-30



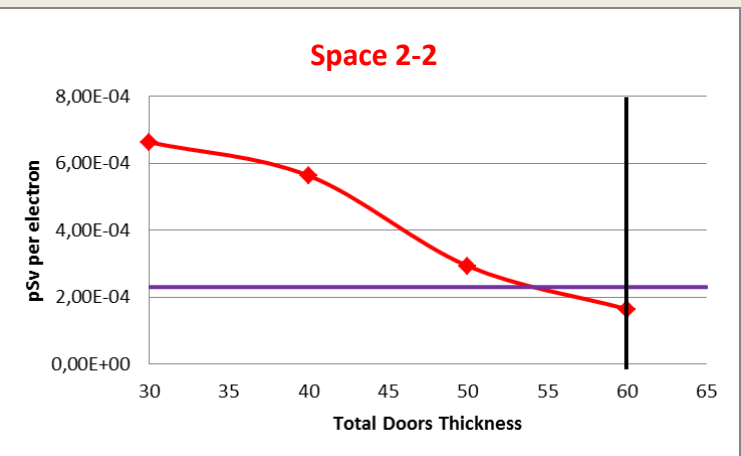
**0,0003 pSv**

All: **0,00114**  
 Elec: 1E-30  
 Phot: 0,00114  
 Neu : 1E-30

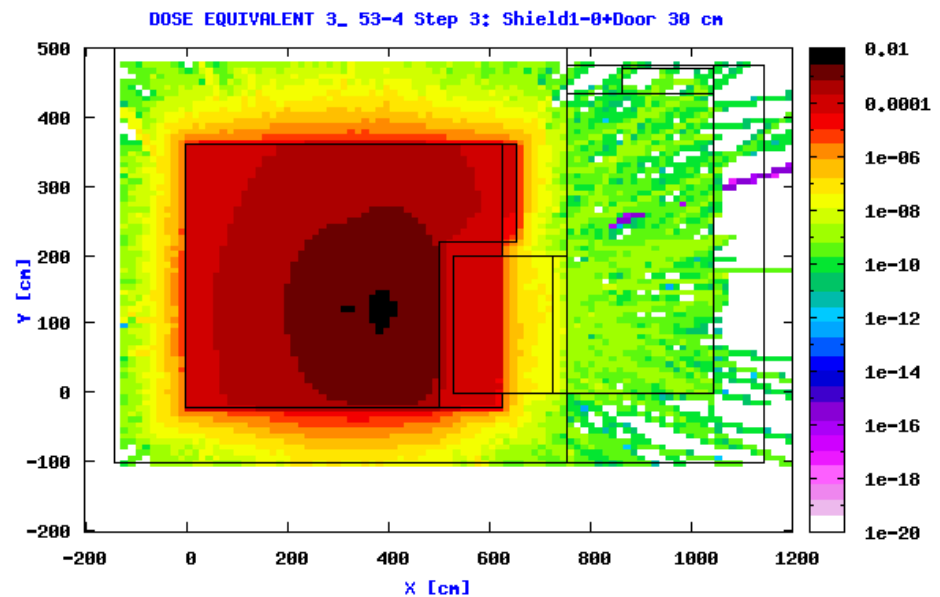
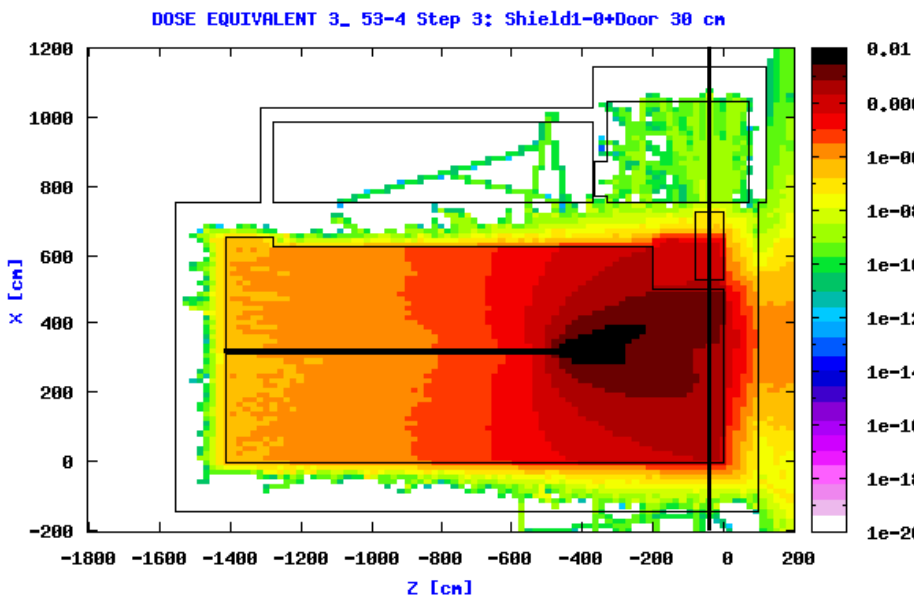
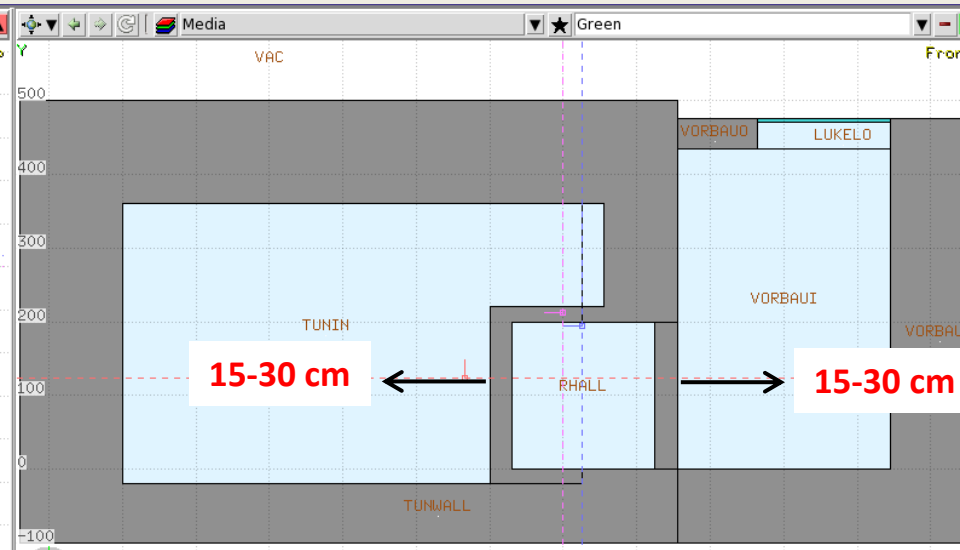
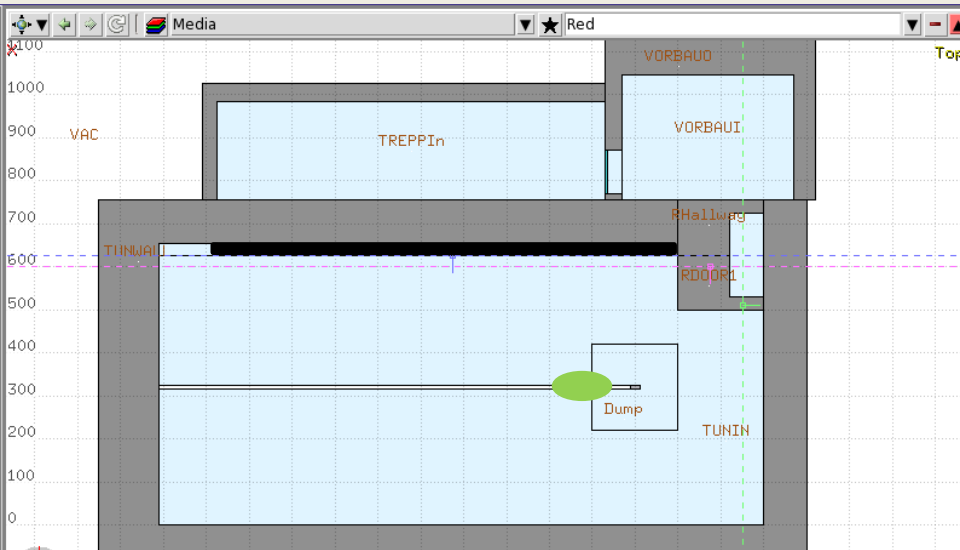


**0,00023pSv**

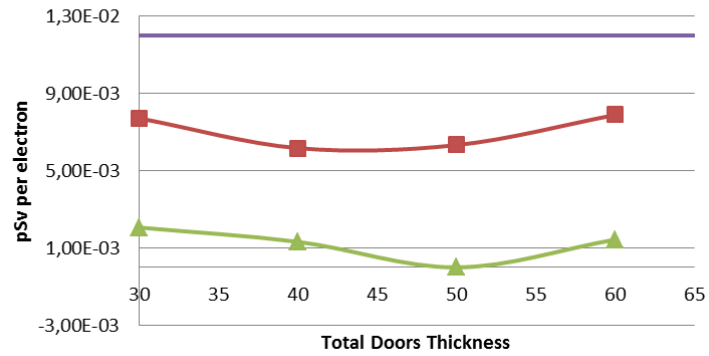
All: **0,00016 pSv**  
 Elec: 1E-30  
 Phot: 0,00016  
 Neu : 1E-30



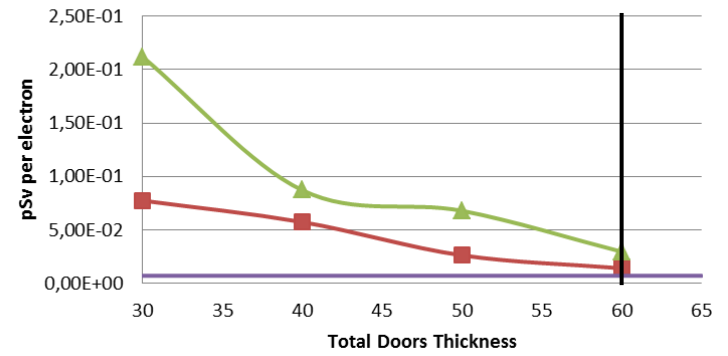
# Design of Shielding 1-0 With Doors



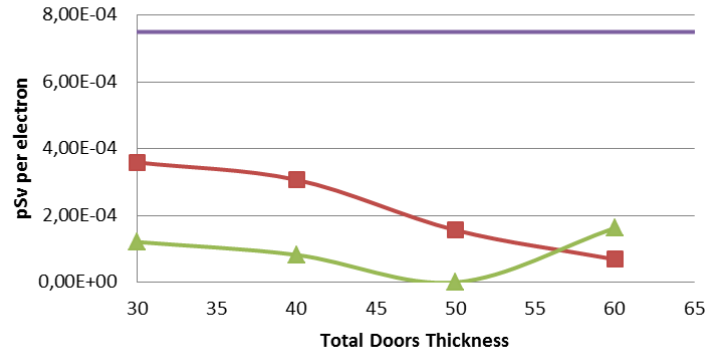
### Room 1



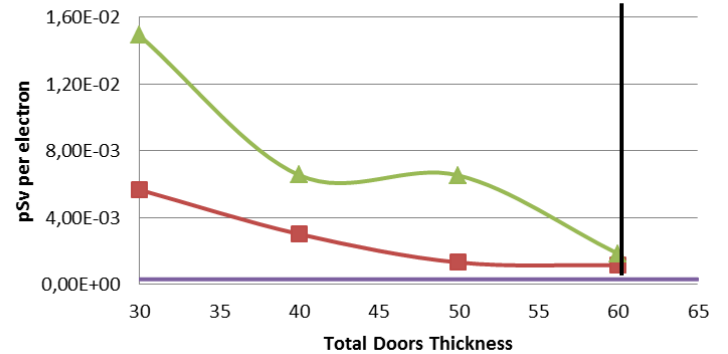
### Room 2



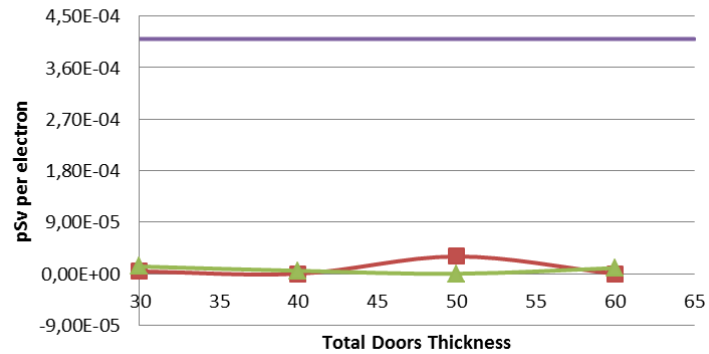
### Space 1-1



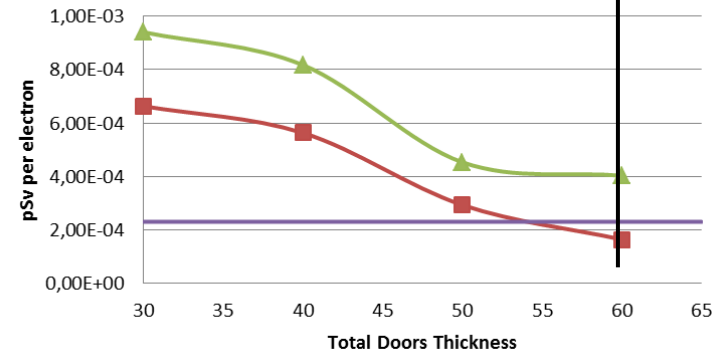
### Space 2-1



### Space 1-2



### Space 2-2



# Design of Shielding 1-0 With Doors and Sandwich

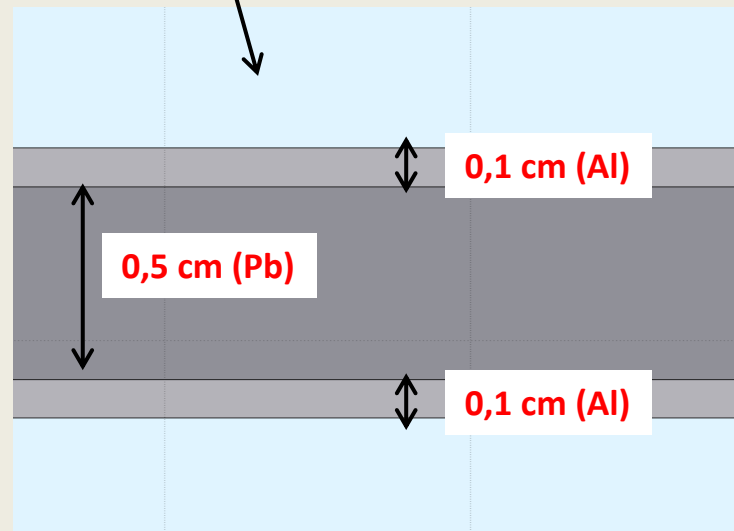
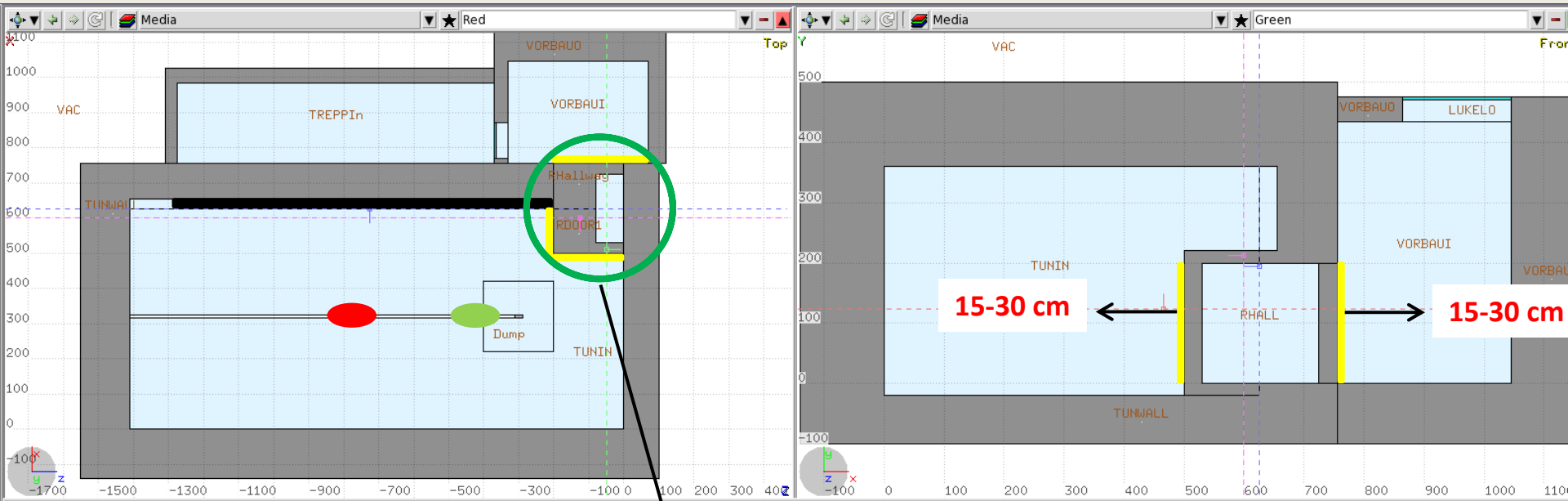
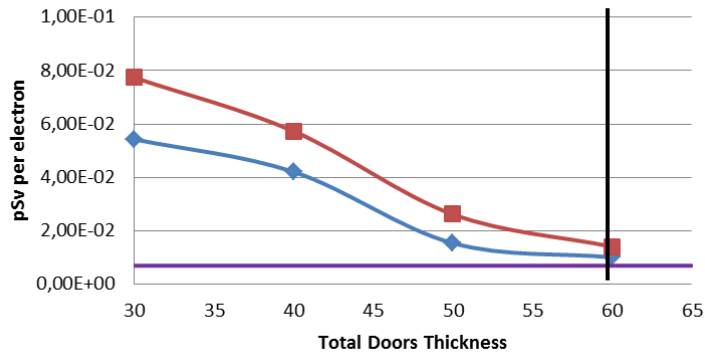
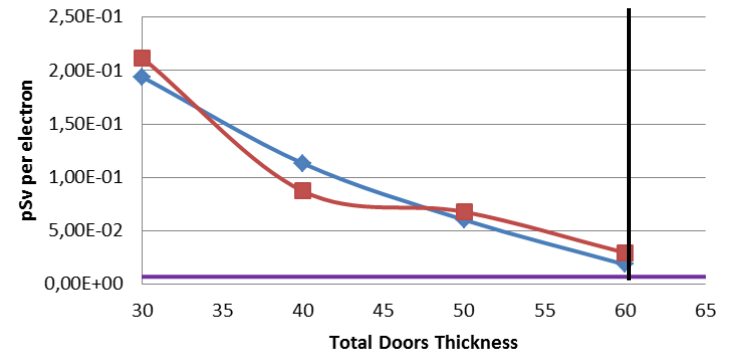


Diagram shielding 1-0 of the tunnel hall in the XZ and YX planes around the pipe.

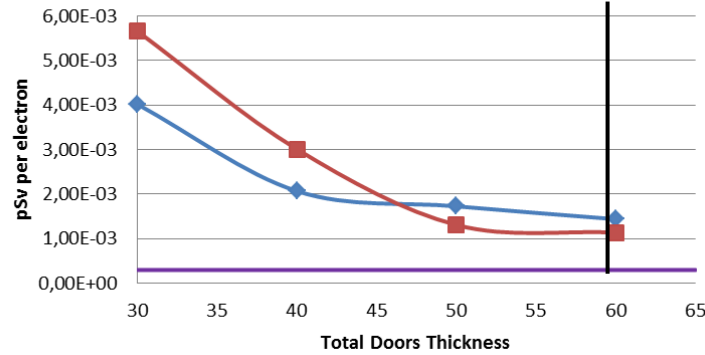
**Room 2: With - Without**



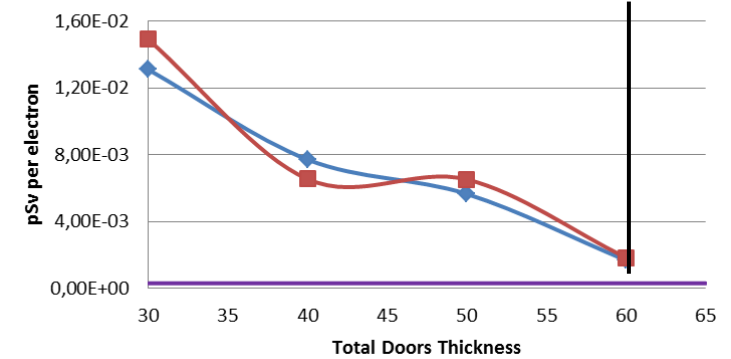
**Room 2: With - Without**



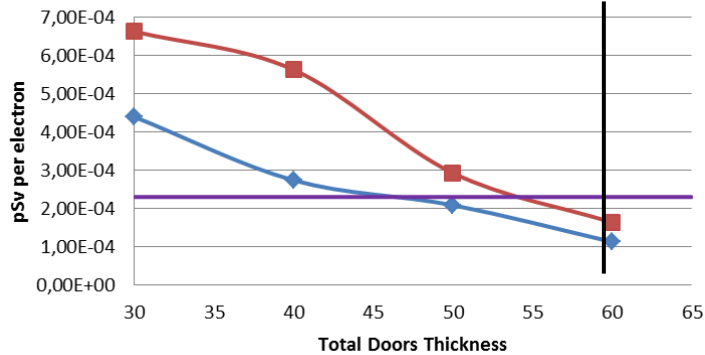
**Space 2-1 : With - Without**



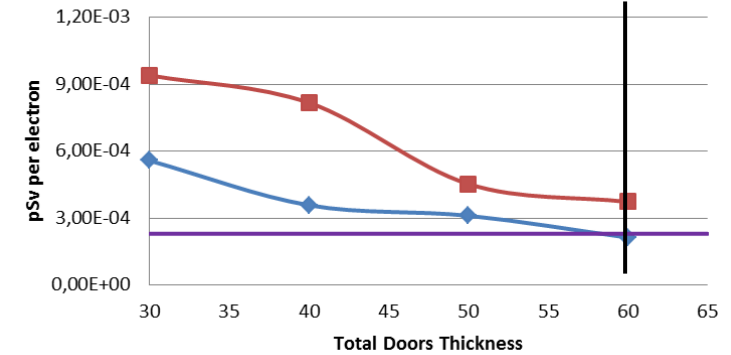
**Space 2-1 : With - Without**



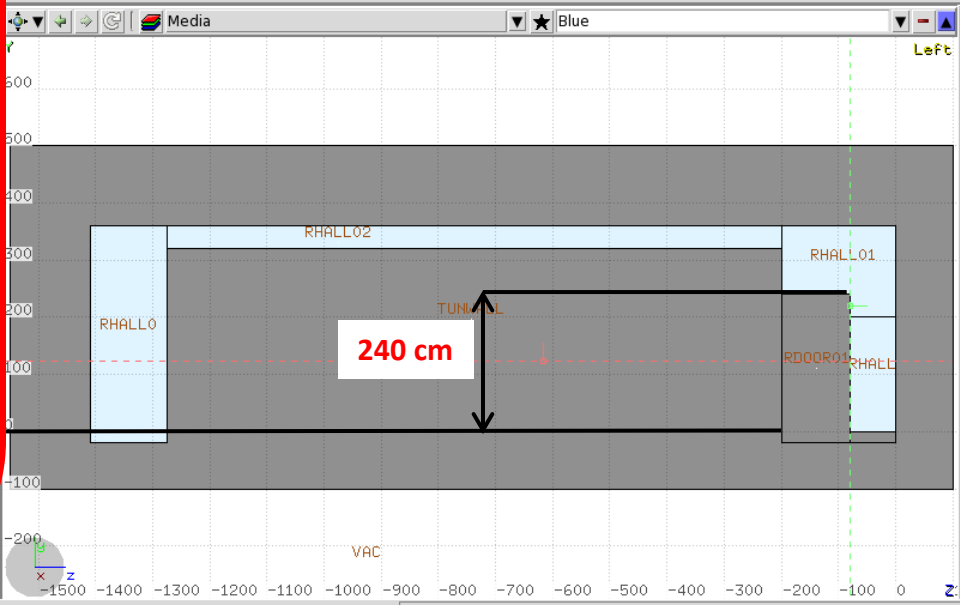
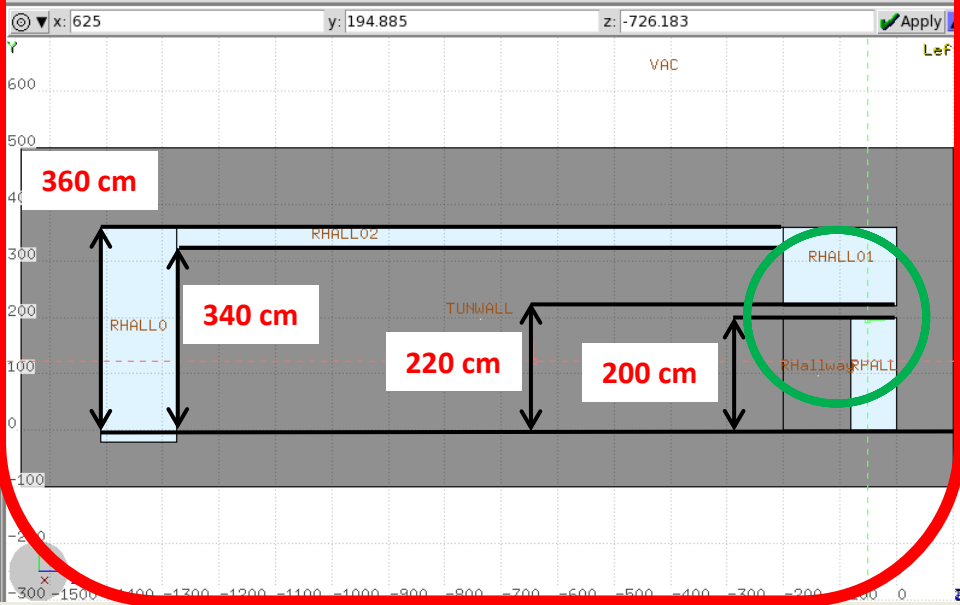
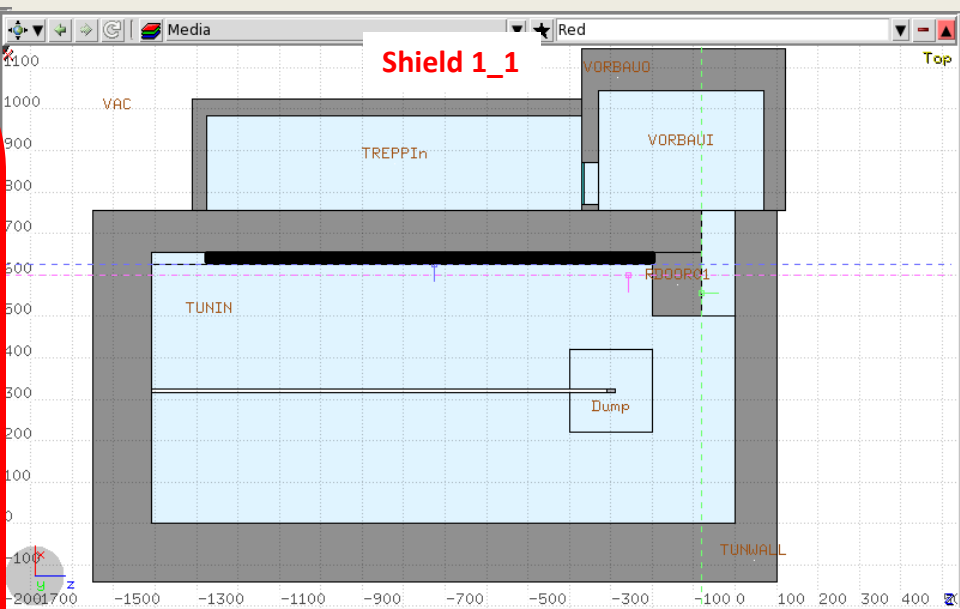
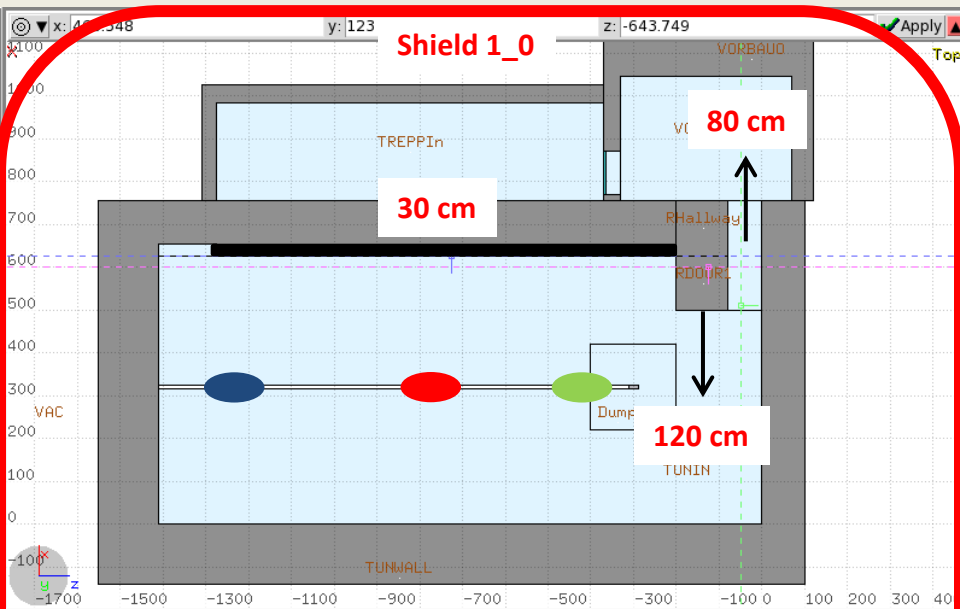
**Space 2-2 : With - Without**



**Space 2-2 : With - Without**

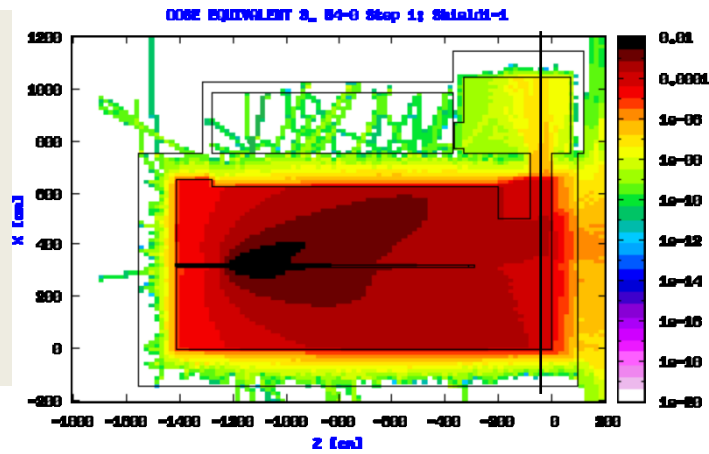


# Shield 1-1: Open



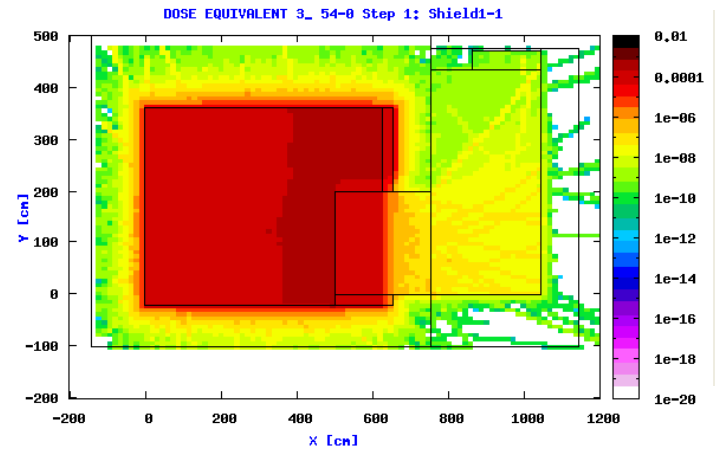


# Equivalent Dose Distribu



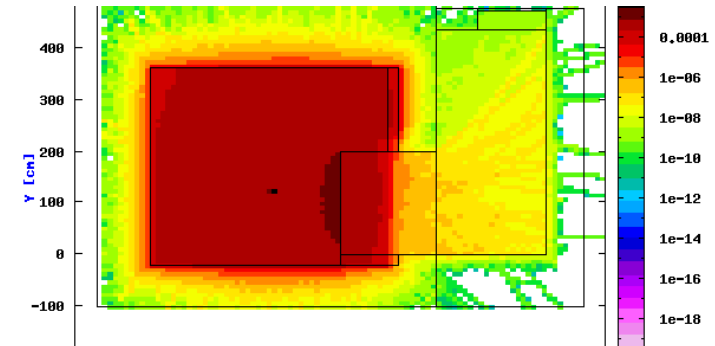
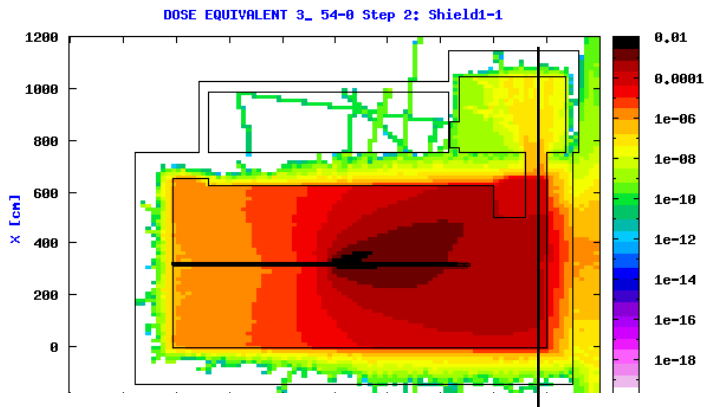
Step 1

Dose: 305202



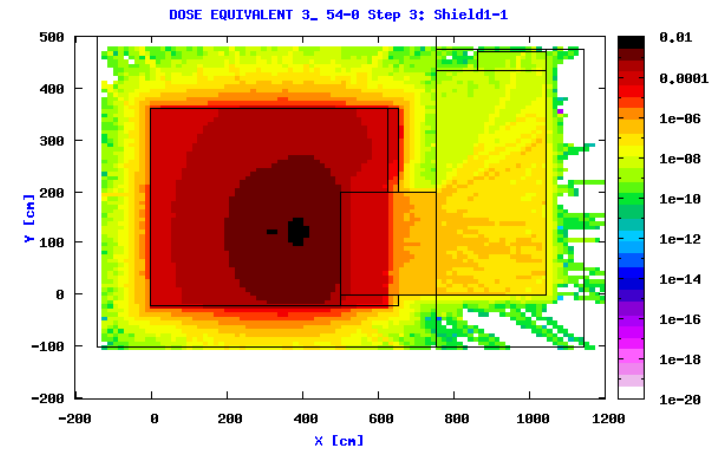
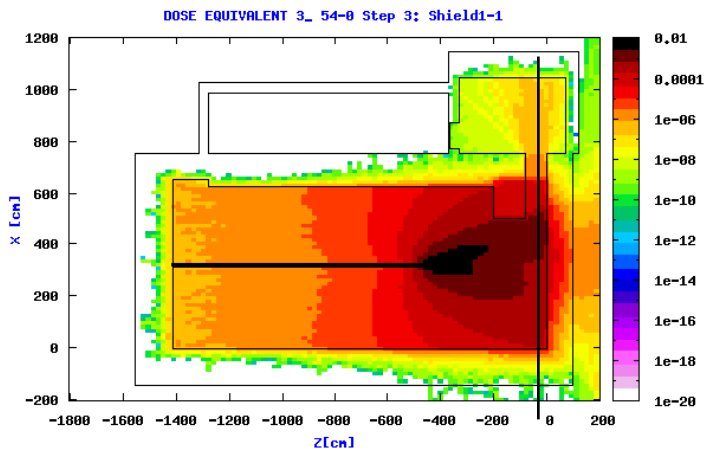
Step 2

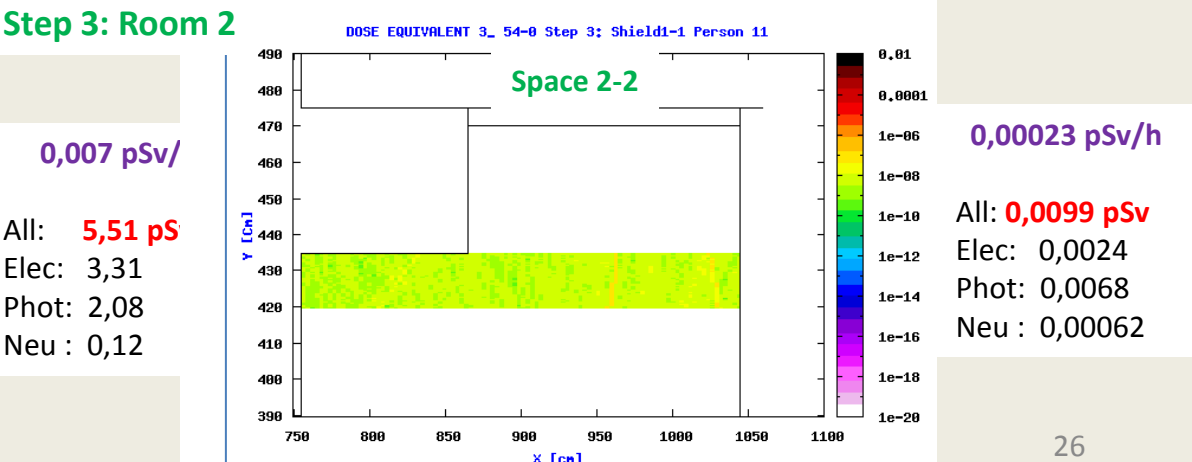
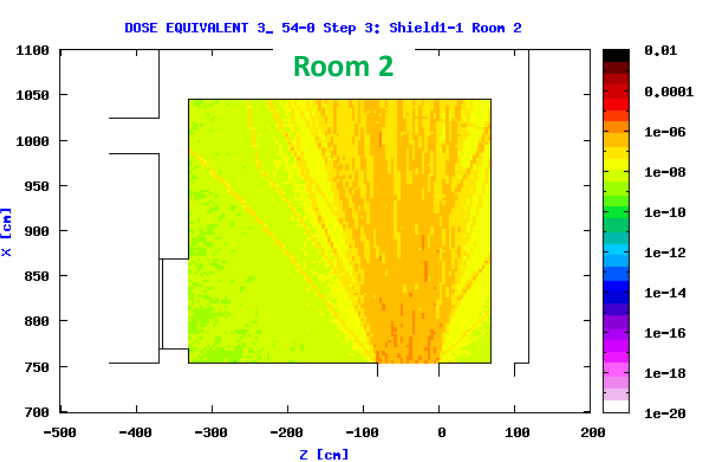
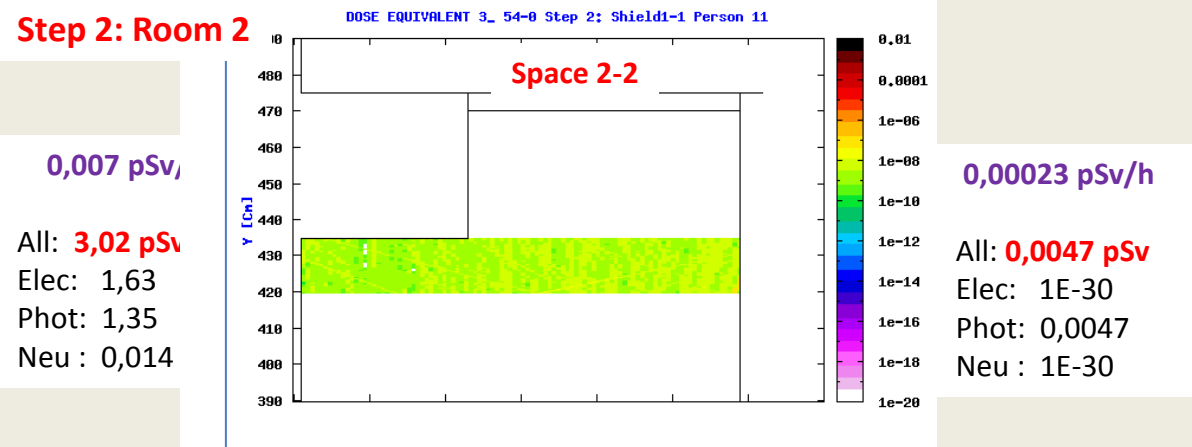
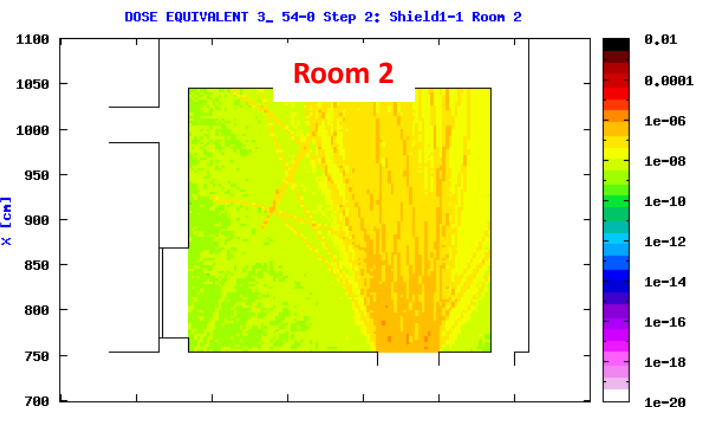
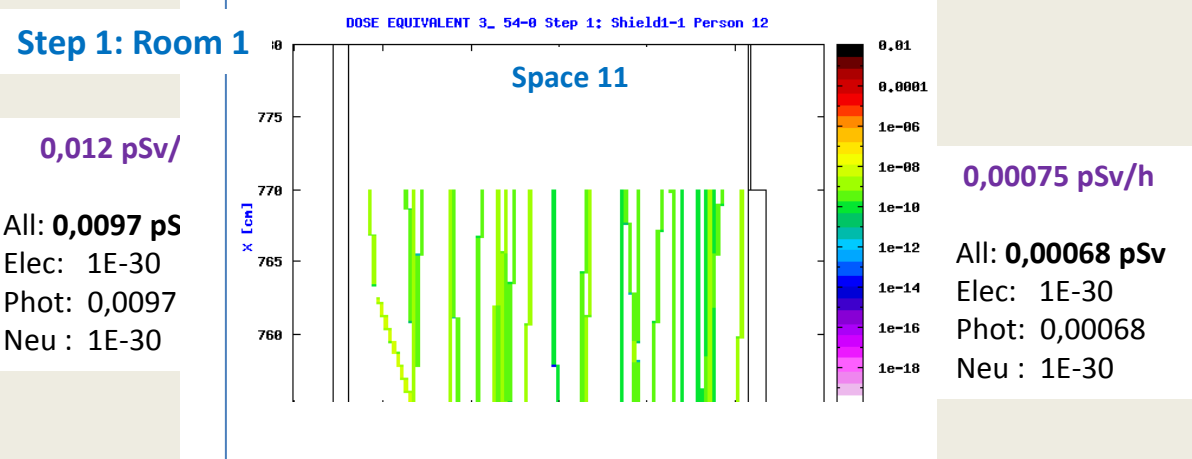
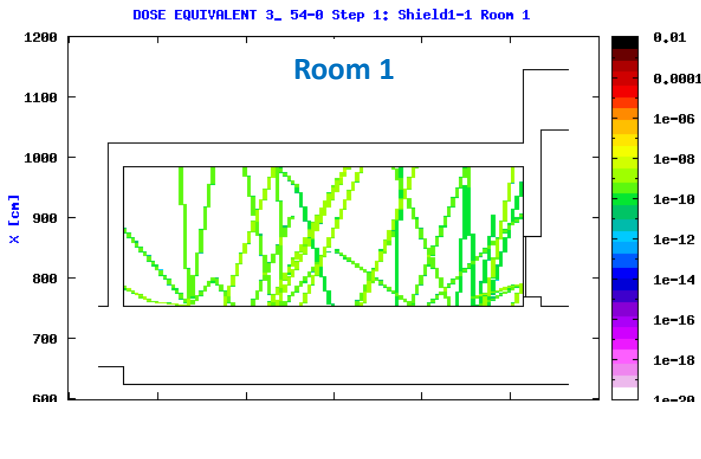
Dose: 394993



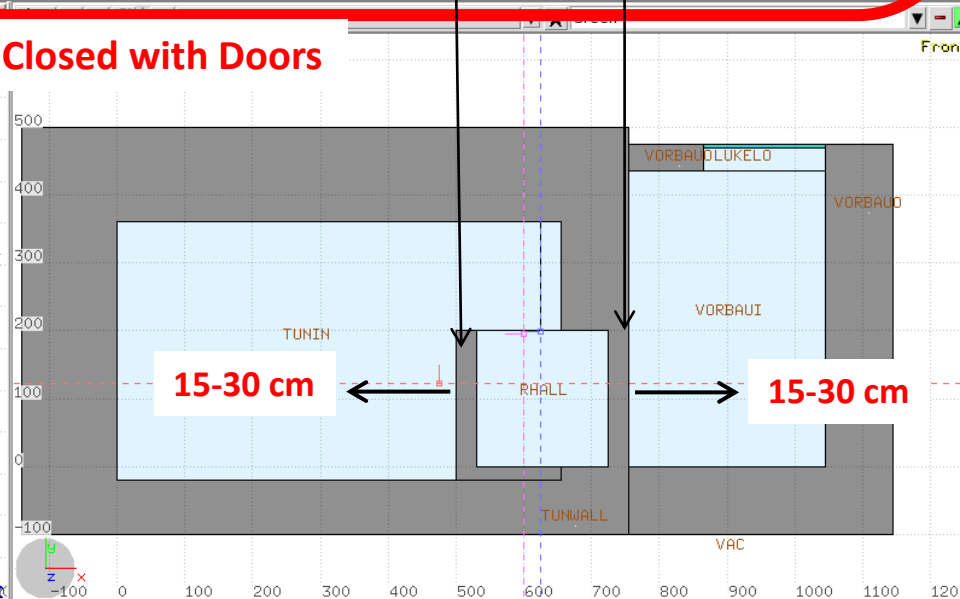
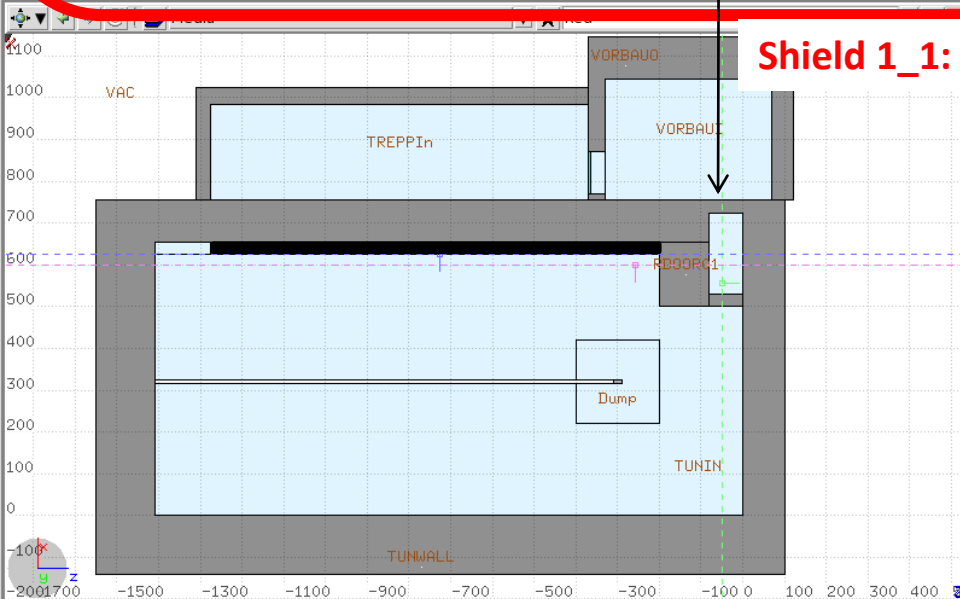
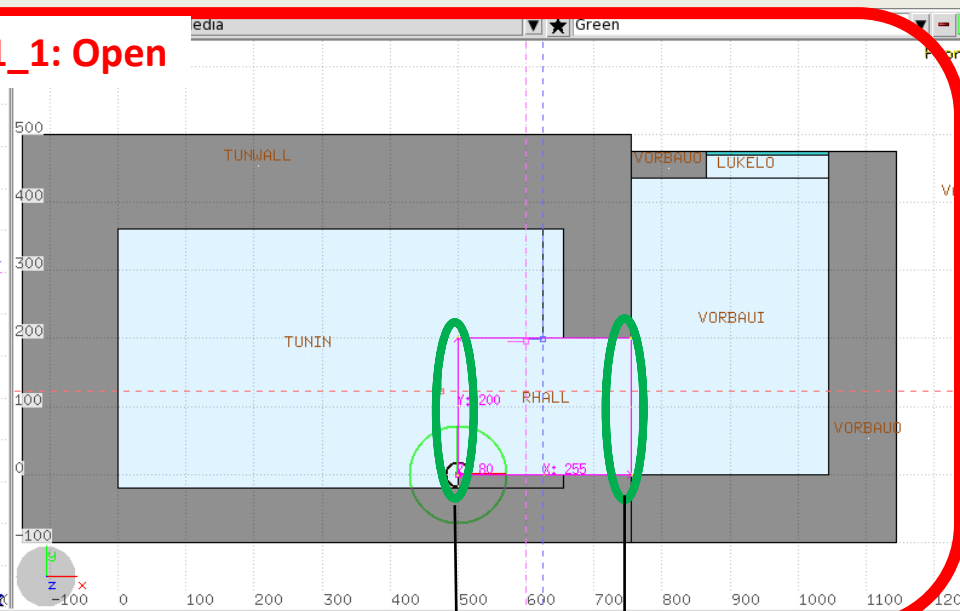
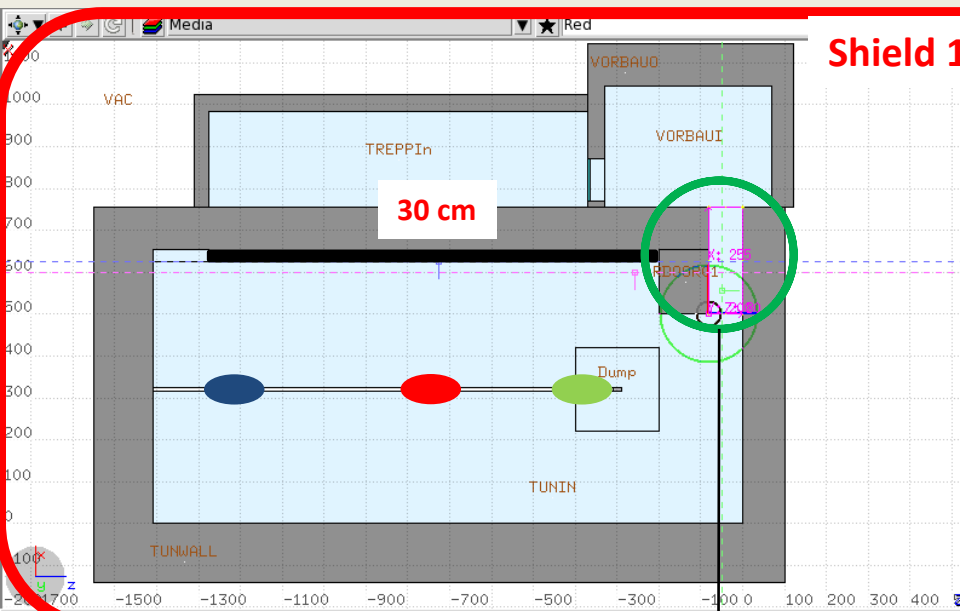
Step 3

Dose: 414217

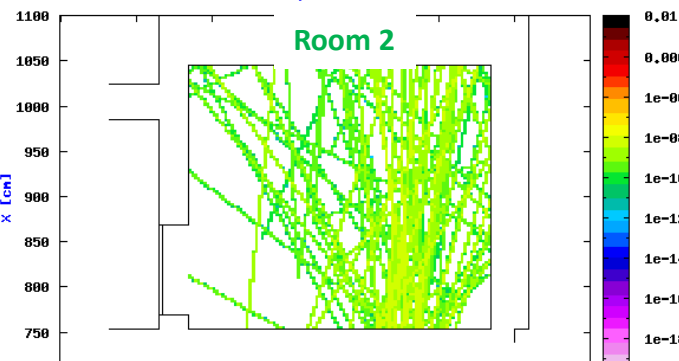




# Shield 1-1: Closed With Doors



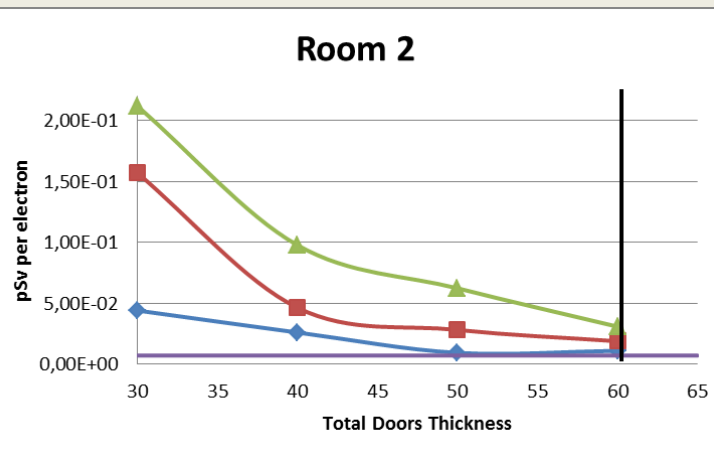
DOSE EQUIVALENT 3\_ 54-4 Step 3: Shield1-1+Door 30 cm; Room 2



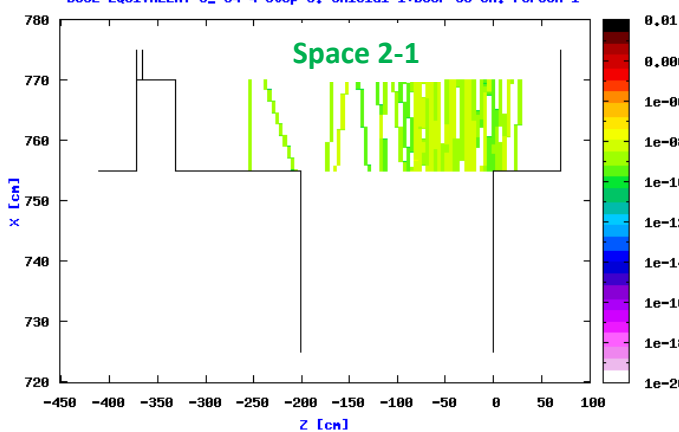
30 cm

0,007 pSv/h

All: **0,031 pSv**  
 Elec: 5,19E-17  
 Phot: 0,0308  
 Neu : 1E-30

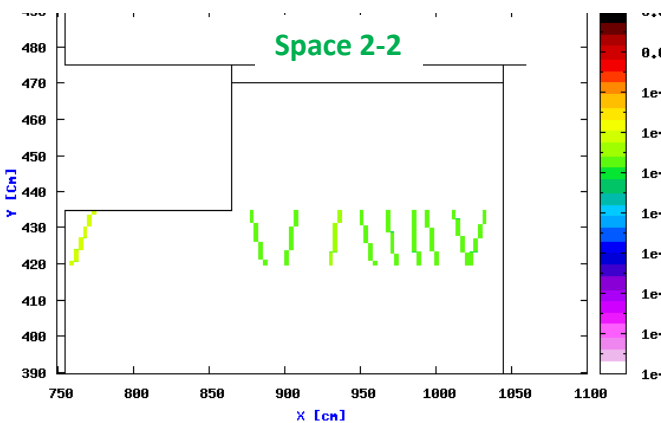
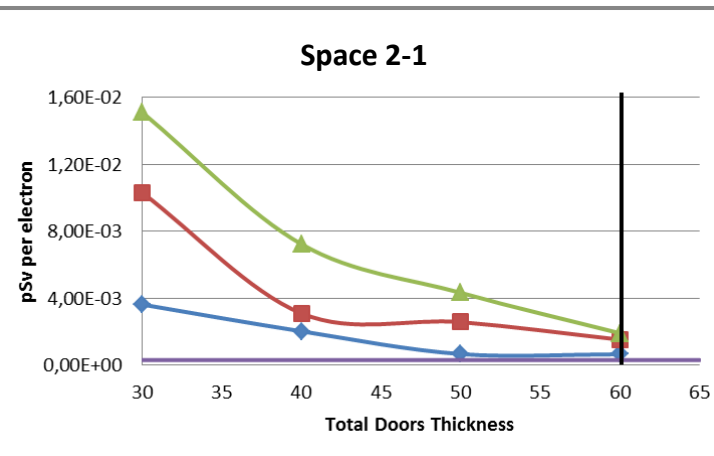


DOSE EQUIVALENT 3\_ 54-4 Step 3: Shield1-1+Door 30 cm; Person 1



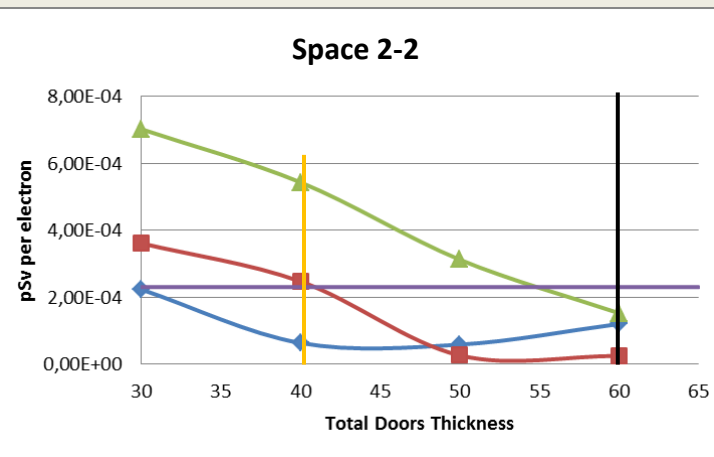
0,0003 pSv/h

All: **0,0019 pSv**  
 Elec: 1E-30  
 Phot: 0,00197  
 Neu : 1E-30

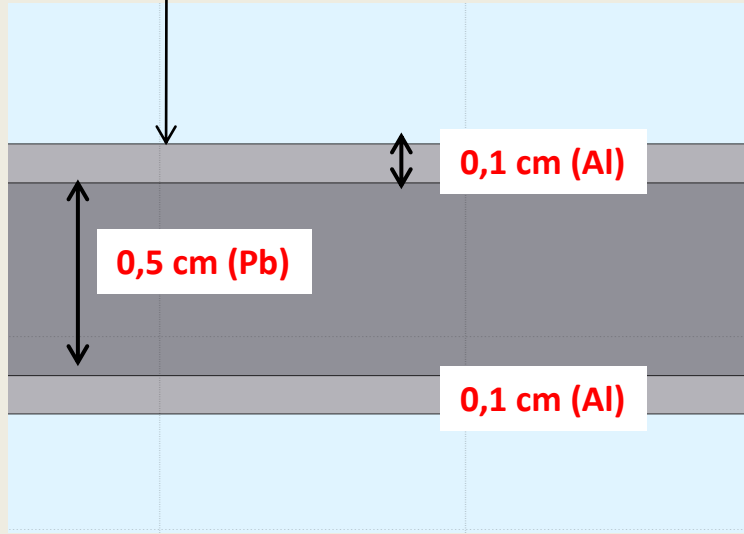
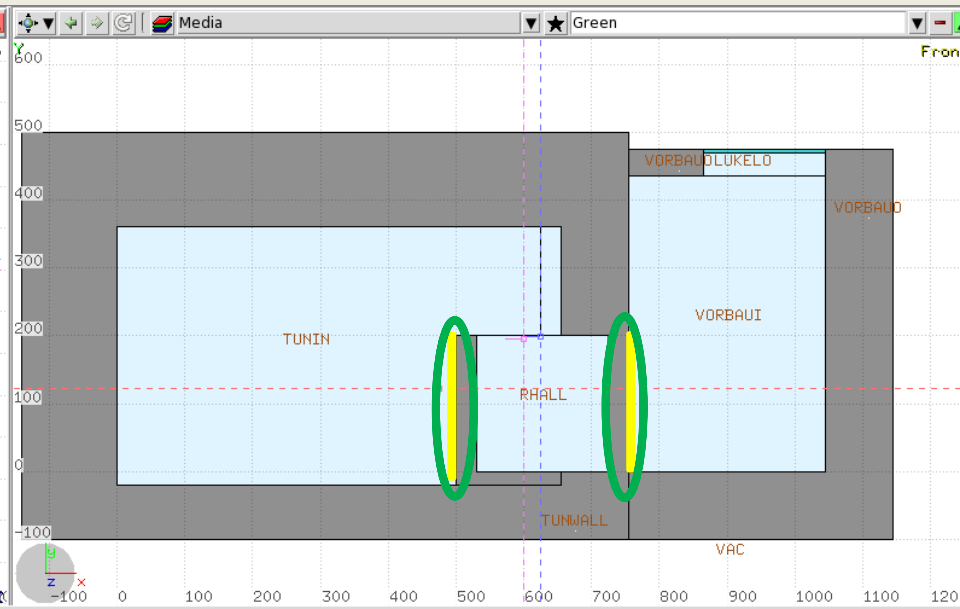
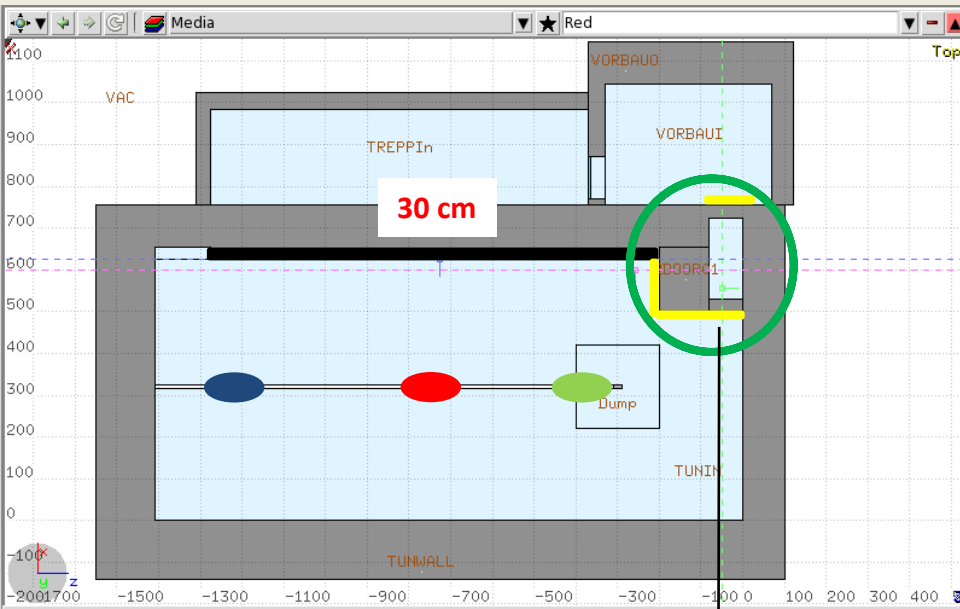


0,00023 pSv/h

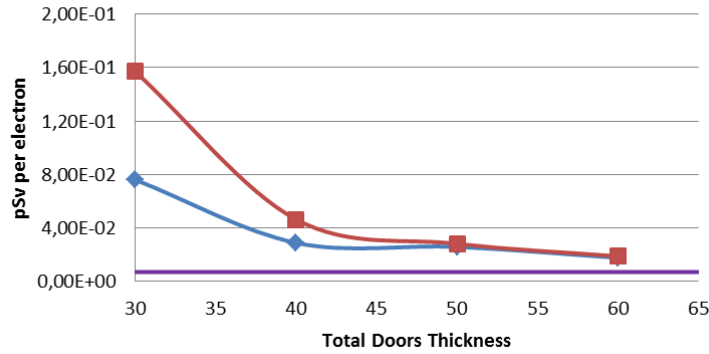
All: **0,00015 pSv**  
 Elec: 1E-30  
 Phot: 0,00015  
 Neu : 1E-30



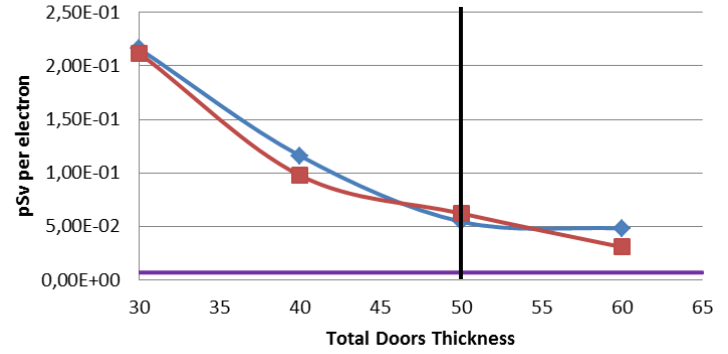
# Shield 1-1: Closed With Doors and Sandwich



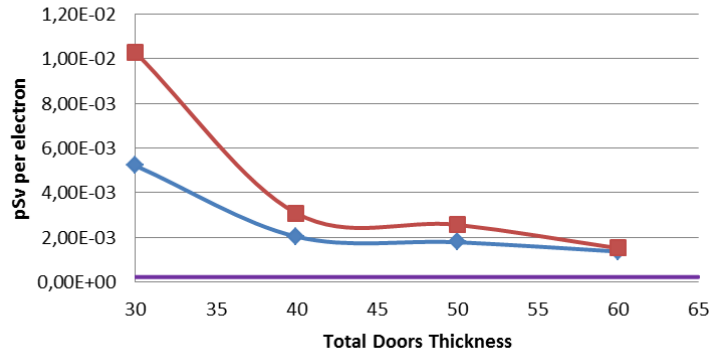
**Room 2 : With - Without**



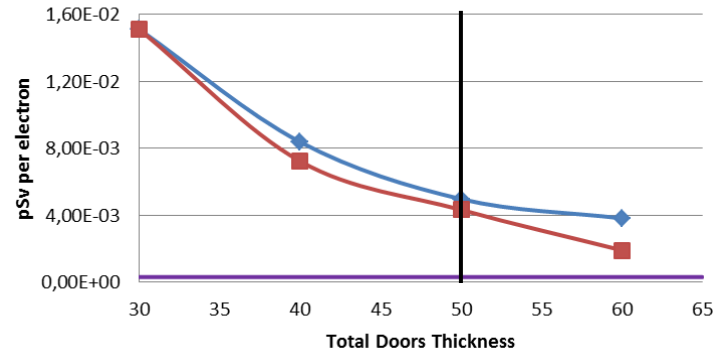
**Room 2 With - Without**



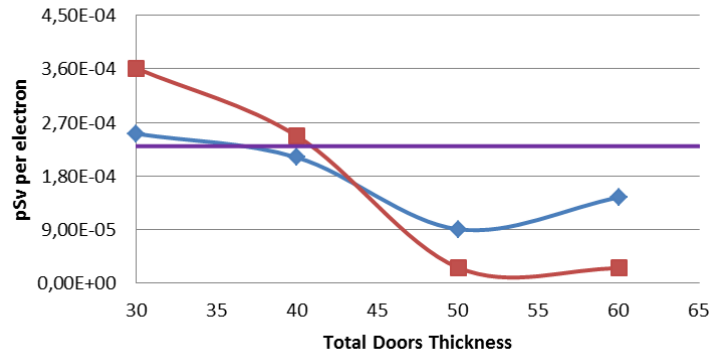
**Space 2-1 : With - Without**



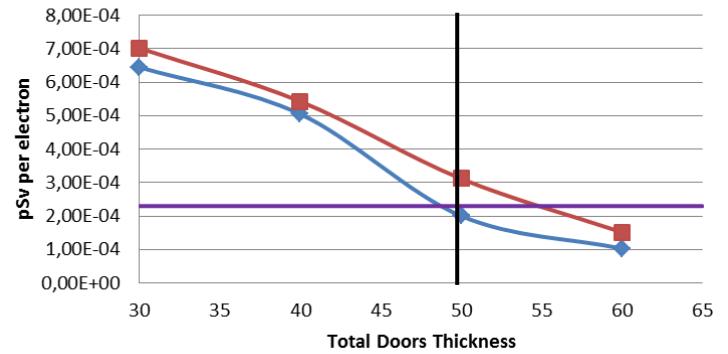
**Space 2-1 : With - Without**



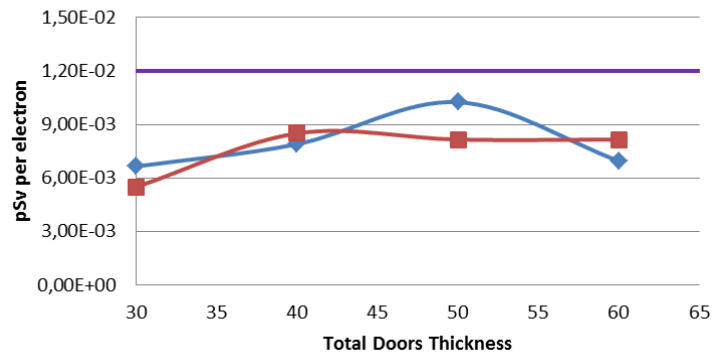
**Space 2-2 : With - Without**



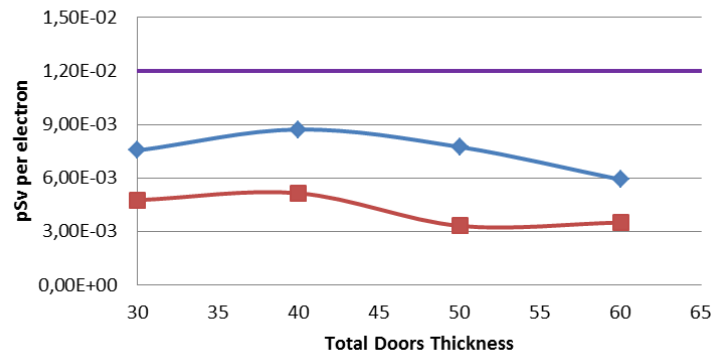
**Space 2-2 : With - Without**



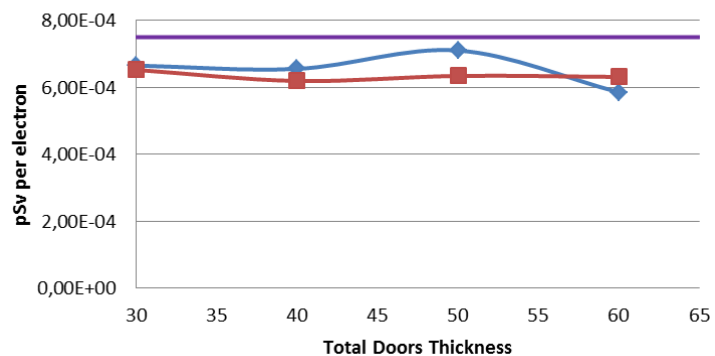
Room 1: With - Without



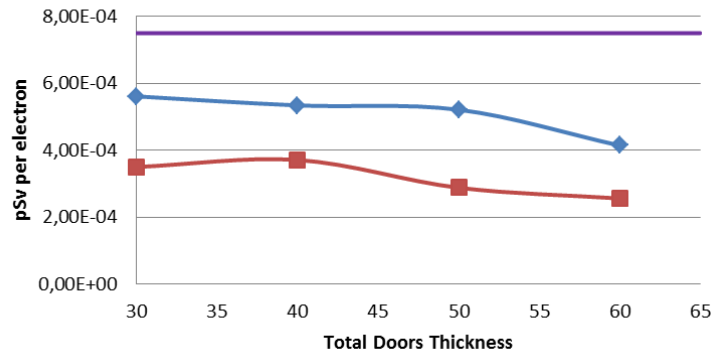
Room 1: With - Without



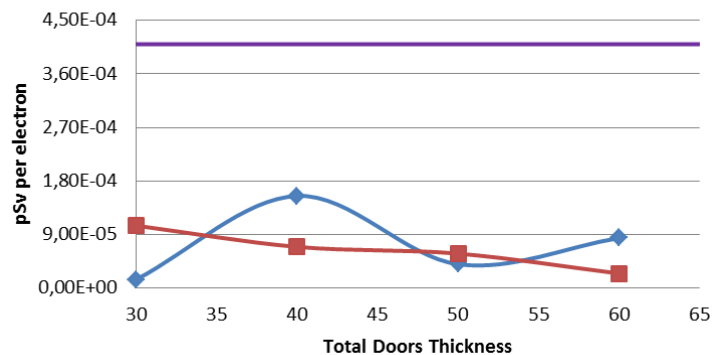
Space 1-1 With - Without



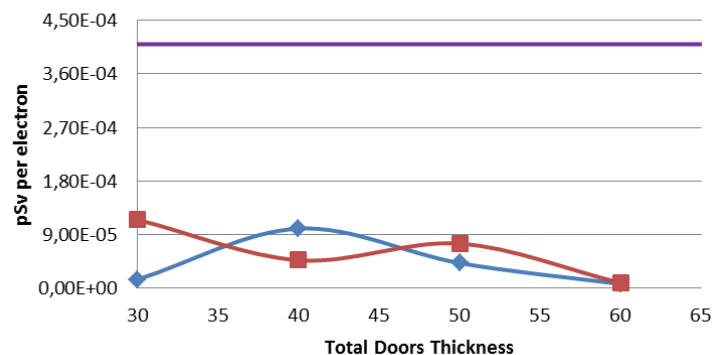
Space 1-1 With - Without



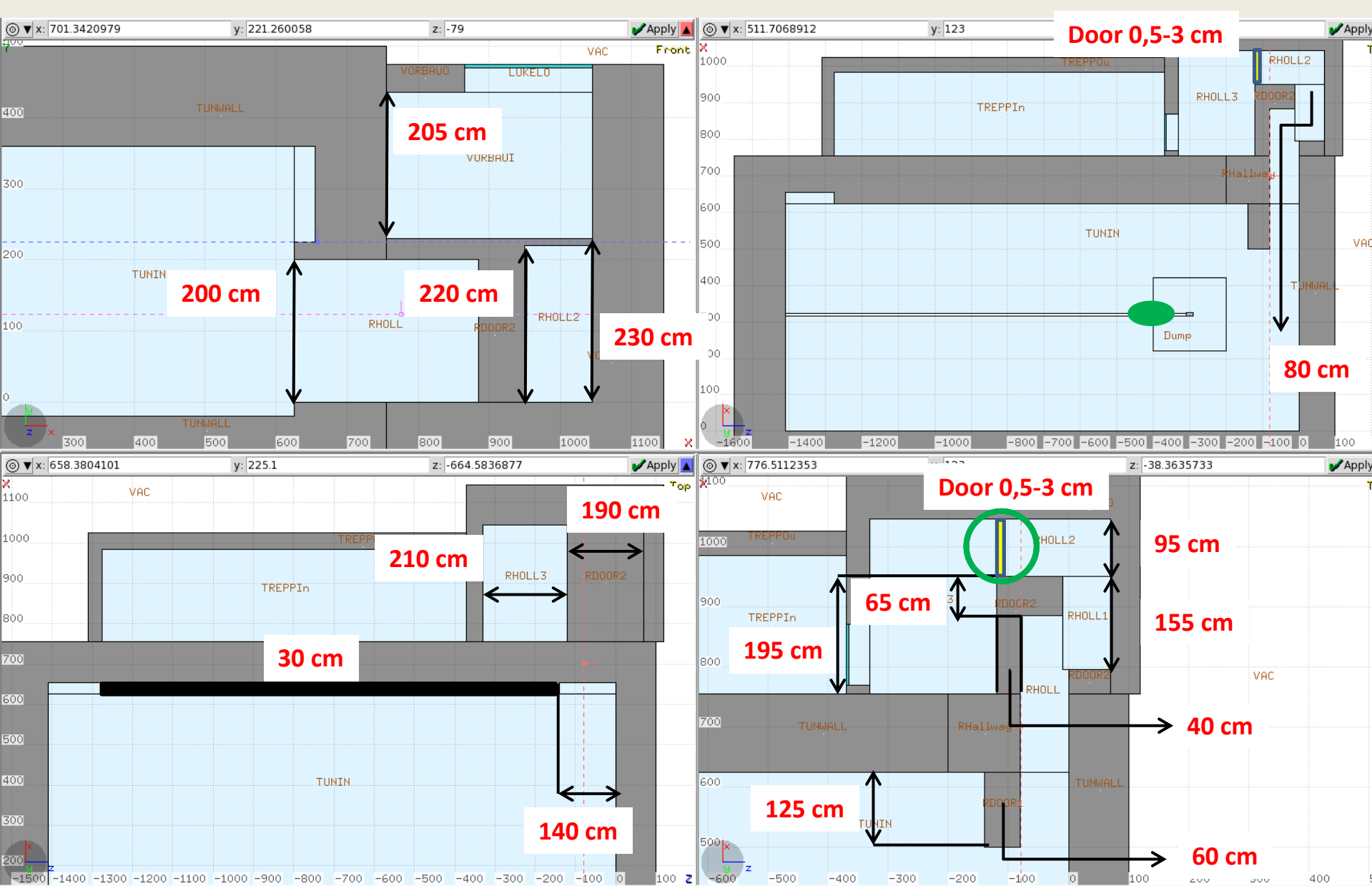
Space 1-2 With - Without



Space 1-2 With - Without

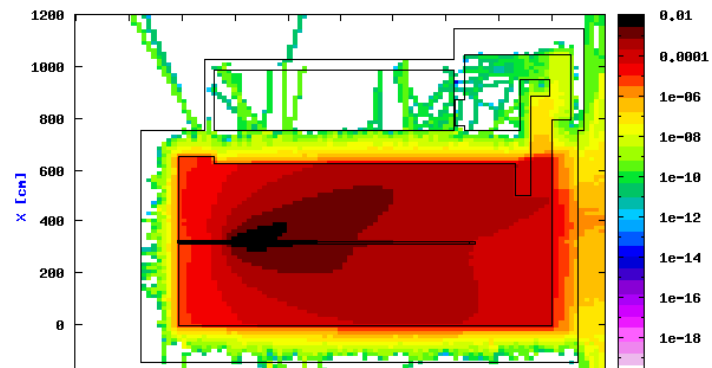


# Design of Shielding 2-0



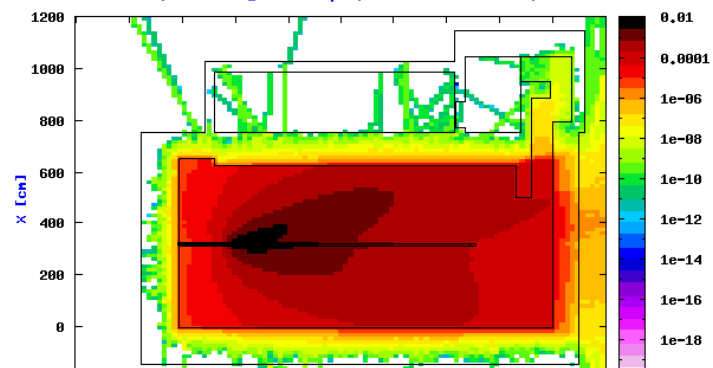


DOSE EQUIVALENT 3\_ 60-0 Step 1: Shield2



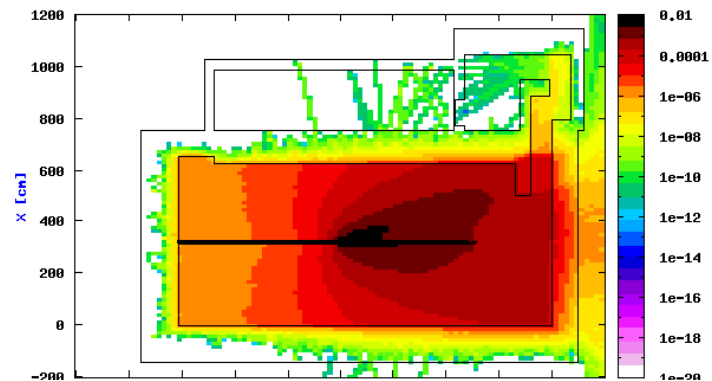
**Step 1**  
**Shield 2**

DOSE EQUIVALENT 3\_ 60-1 Step 1: Shield2+Door3 (Fe 0.5cm)



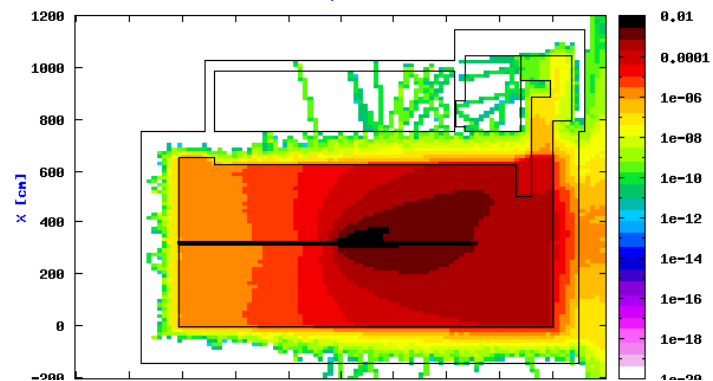
**Step 1**  
**Shield 2+Door**

DOSE EQUIVALENT 3\_ 60-0 Step 2: Shield2



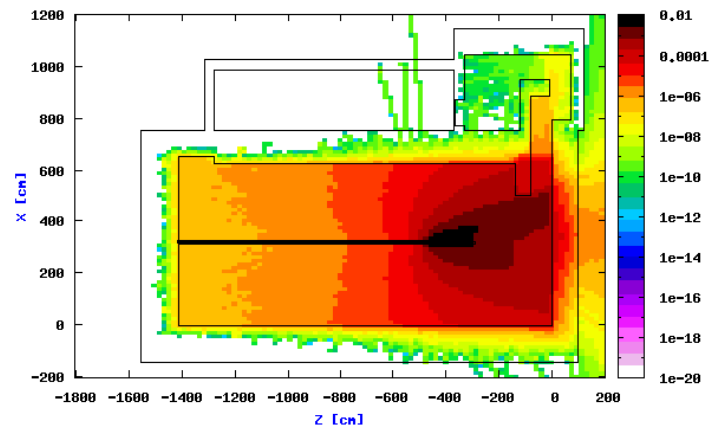
**Step 2**

DOSE EQUIVALENT 3\_ 60-1 Step 2: Shield2+Door3 (Fe 0.5cm)



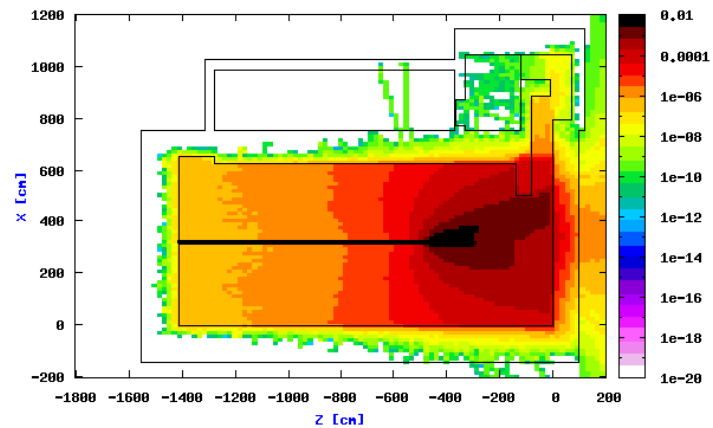
**Step 2**

DOSE EQUIVALENT 3\_ 60-0 Step 3: Shield2

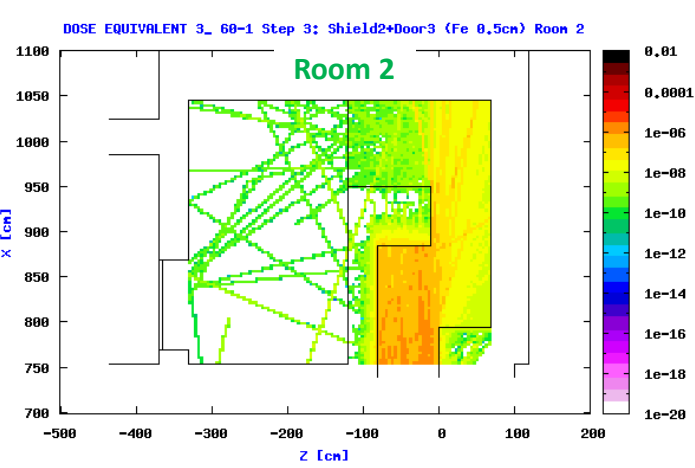


**Step 3**

DOSE EQUIVALENT 3\_ 60-1 Step 3: Shield2+Door3 (Fe 0.5cm)

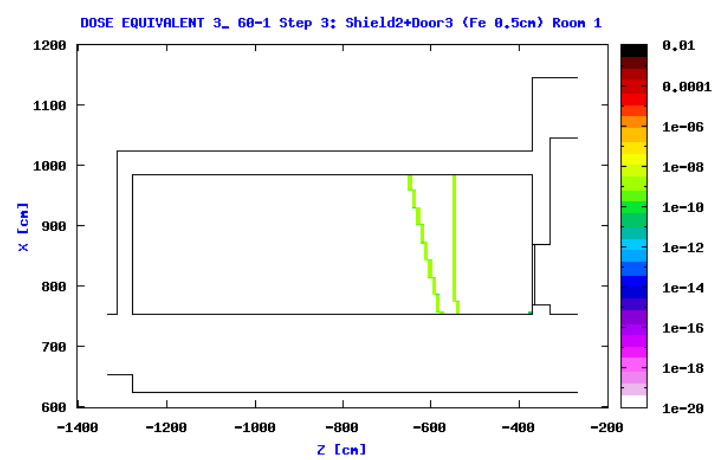


**Step 3**



### Step 3: Room

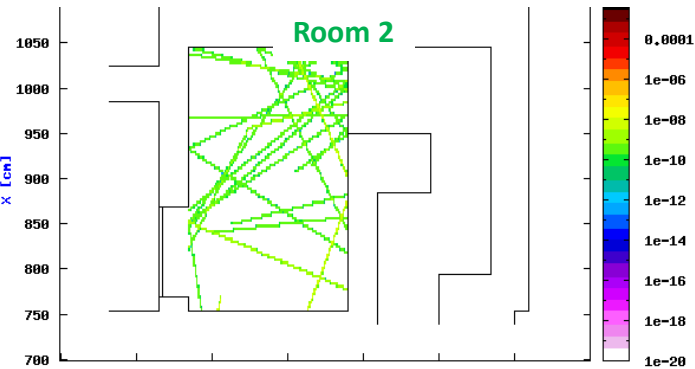
All: **2,72 pSv**  
 Elec: 1E-30  
 Phot: 2,72  
 Neu : 1E-30



### Step 3: Room 1

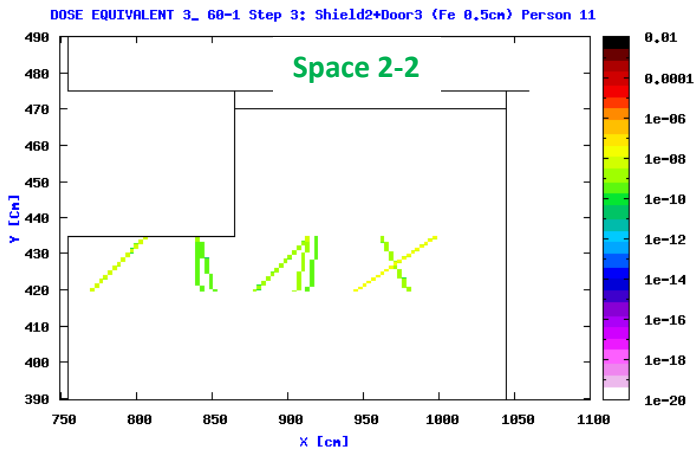
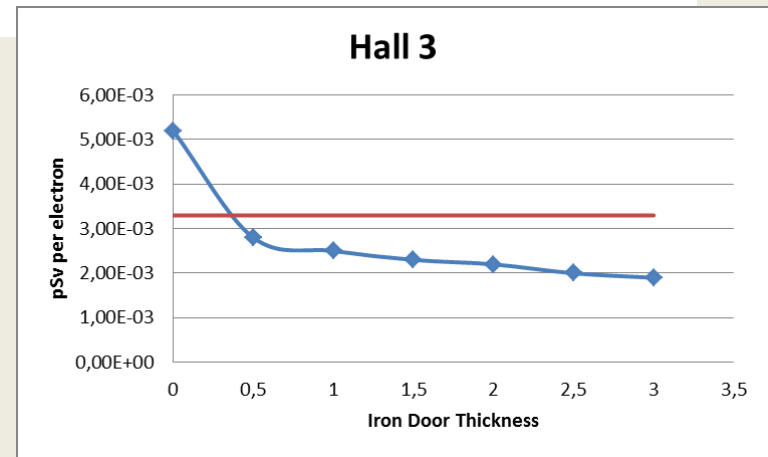
**0,012 pSv/h**

All: **0,0018 pSv**  
 Elec: 1E-30  
 Phot: 0,0027  
 Neu : 1E-30



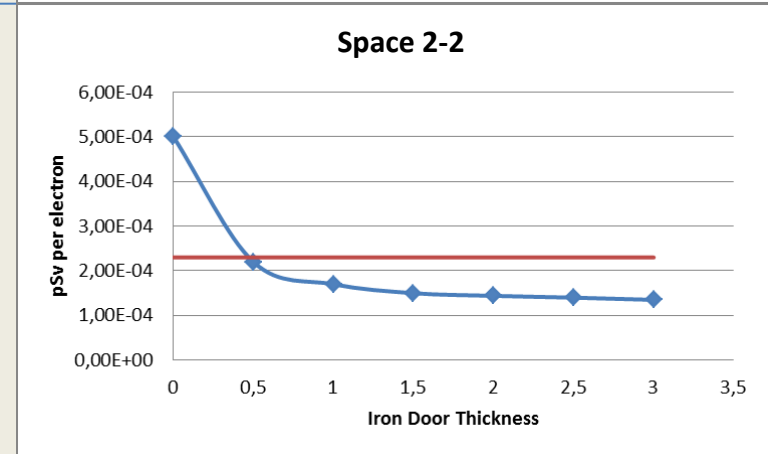
**0,0033 pSv**

All: **0,0028 pSv**  
 Elec: 1E-30  
 Phot: 0,0028  
 Neu : 1E-30



**0,00023 pSv**

All: **0,00022**  
 Elec: 1E-30  
 Phot: 0,00022  
 Neu : 1E-30





## Next Steps

- Improve simulation results using FLUKA custom routines.
  - Input the beam characteristics: energy spread, divergence, beam profile (x, y direction)
  - Repeat the simulation with the beam parameters
  - Compare the simulation results with the old one.
  - Repeat the simulation with complex geometry.
  - Analyzing data from mgdraw.f to find better types of shielding materials and thickness
  - Using routine source.f in input, adequate to read particle distribution provided by tracking simulations and correctly place it in the geometry.

## Conclusion

- For 1  $\mu\text{A}$  beam a feasible section was found. For 75  $\mu\text{A}$  (operation permission) this does not work
- Shielding 1-0: in order to have dose less than 3  $\mu\text{Sv/h}$  on ceiling of the room 2, 30 cm door with sandwich should be used.
- Shielding 1-1: only door 30 cm or 25 cm door with sandwich should be used.
- Shielding 2: the room 2 is not controlled area.

### Alternatively

- Some area have to be declared 'controlled area' with levels of 30-50  $\mu\text{Sv/h}$  during operation with 1  $\mu\text{A}$  beams
- For higher beam current operation the dose levels have to be monitored

**Thank You for Attention !**