Radiation challenges of primary cooling return water

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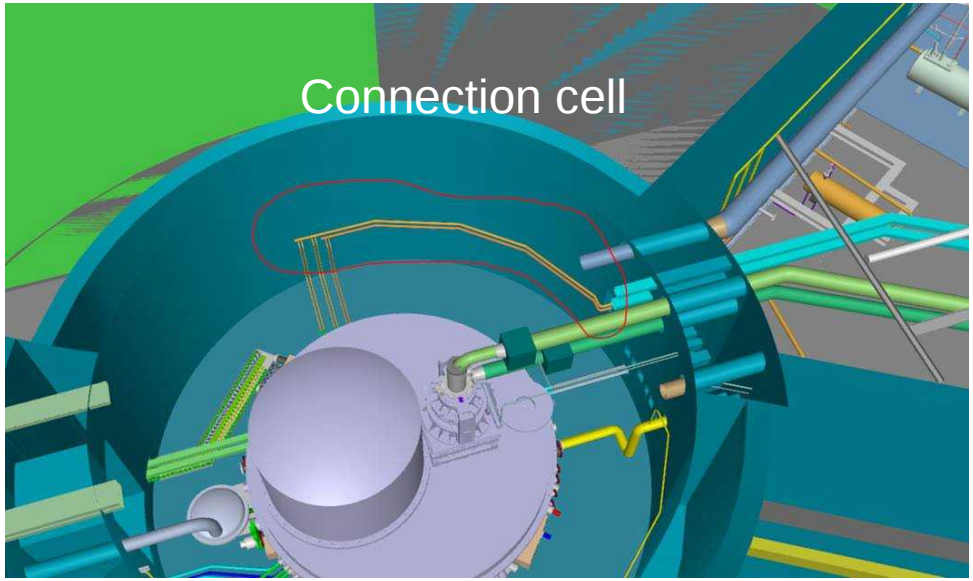
Motivation

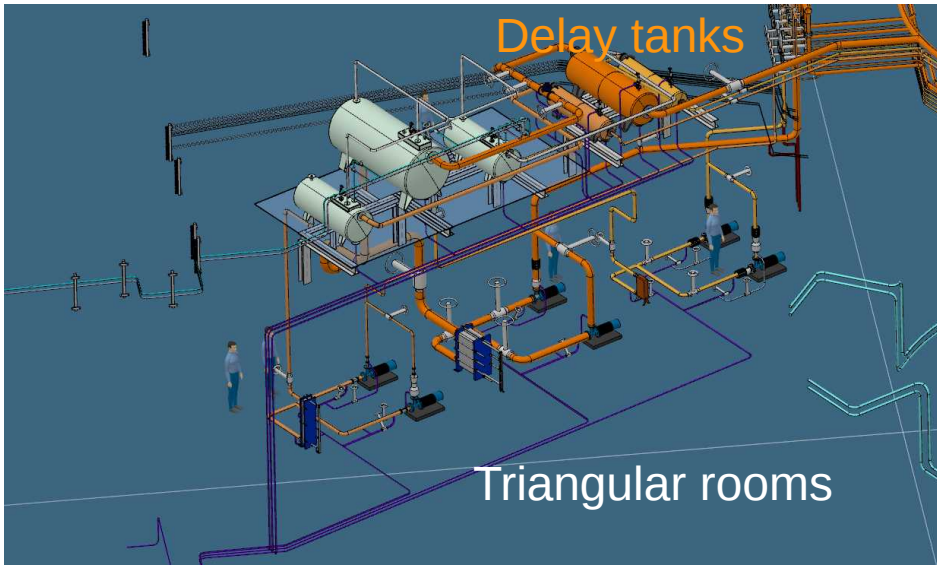
- **Assess biological dose rates in:**
  - **Connection Cell**
  - **Utilities rooms (triangular rooms)**
  - **Instrument hall**

  from activated primary cooling water

- **Adjust shielding to meet requirements**

Water circuit overview

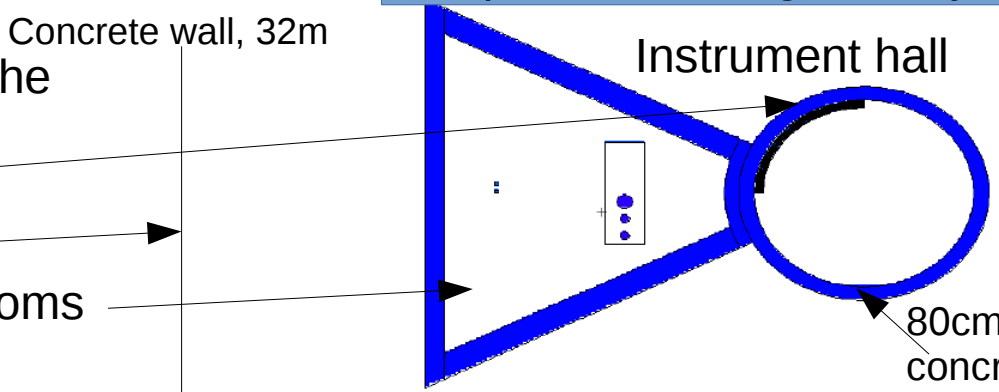




During operations, requirements on the biological dose-rate are:

- 3μSv/h in the instrument hall
- 3μSv/h at the “32m” wall
- 25μSv/h adjacent the triangular rooms

Simplified MCNP geometry



Methods

- Using the *MCNP* Master Model, all water cells in the reflector plug are combined including impurities*, and the activity is calculated at different times using CINDER'90 (v1.05)

Irradiation history

Time step

1. 2700h: 2GeV, 2.5mA proton beam on target
2. 1680h: Beam off.
3. 2700h: 2GeV, 2.5mA proton beam on target
4. 1680h: Beam off.
5. 2700h: 2GeV, 2.5mA proton beam on target
6. 1680h: Beam off.
7. 2700h: 2GeV, 2.5mA proton beam on target

Delay tank relevant

8. 0s cooling time
9. 30s cooling time
10. 60s cooling time
11. 90s cooling time
12. 120s cooling time

Maintenance relevant

13. 1h cooling time
14. 4h cooling time
15. 1d cooling time
16. 7d cooling time
17. 1y cooling time

- Source term prepared for each time step using *gamma script*
- *Gamma transport calculations results in biological dose-rate maps using ICRP-116 fluence-to-dose conversion factors*
- *Full source term describes the total activity resulting from ~2years of running.*
  - *A good representation of the long lived isotopes.*
  - *Modeling is static => depending on subsystem: full source term is a poor representation of the short lived*

*) ESS-0045043

Inventory

Relevant for delay tank

Isotope	Half-life [s]	Decay mode	Time step 8 [0s]	Time step 9 [30s]	Time step 10 [60s]	Time step 11 [90s]	Time step 12 [120s]
^{3}H	3.89E8	β	621.3	621.3	621.3	621.3	621.3
^{7}Be	4.61E6	EC$\beta+\gamma[477keV]$	445.1	445.1	445.1	445.1	445.1
^{11}C	1223	β	1473	1449	1424	1400	1377
^{14}O	70.6	$\beta+\gamma[2.3MeV]$	92.3	69.4	51.7	38.5	28.7
^{15}O	122	β	4511	3827	3228	2723	2297
^{16}N	7.1	$\beta+\gamma[6.1MeV]$	4462	266.1	14.4	0.8	0.04
Total			12380	7161	6234	5657	5180

Relevant for maintenance

Isotope	Half-life [s]	Decay mode	Time step 13 [1h]	Time step 14 [4h]	Time step 15 [1d]	Time step 16 [7d]	Time step 17 [1y]
^{3}H	3.89E8	β	621.3	621.3	621.2	620.6	587.3
^{7}Be	4.61E6	EC$\beta+\gamma[477keV]$	444.9	444.2	439.4	406.4	3.9
^{11}C	1223	β	191.6				
^{14}O	70.6	$\beta+\gamma[2.3MeV]$					
^{15}O	122	β					
Total			1270	1070	1060	1030	592

Activities in *Curie*. Only main contributers listed - “Total” includes all

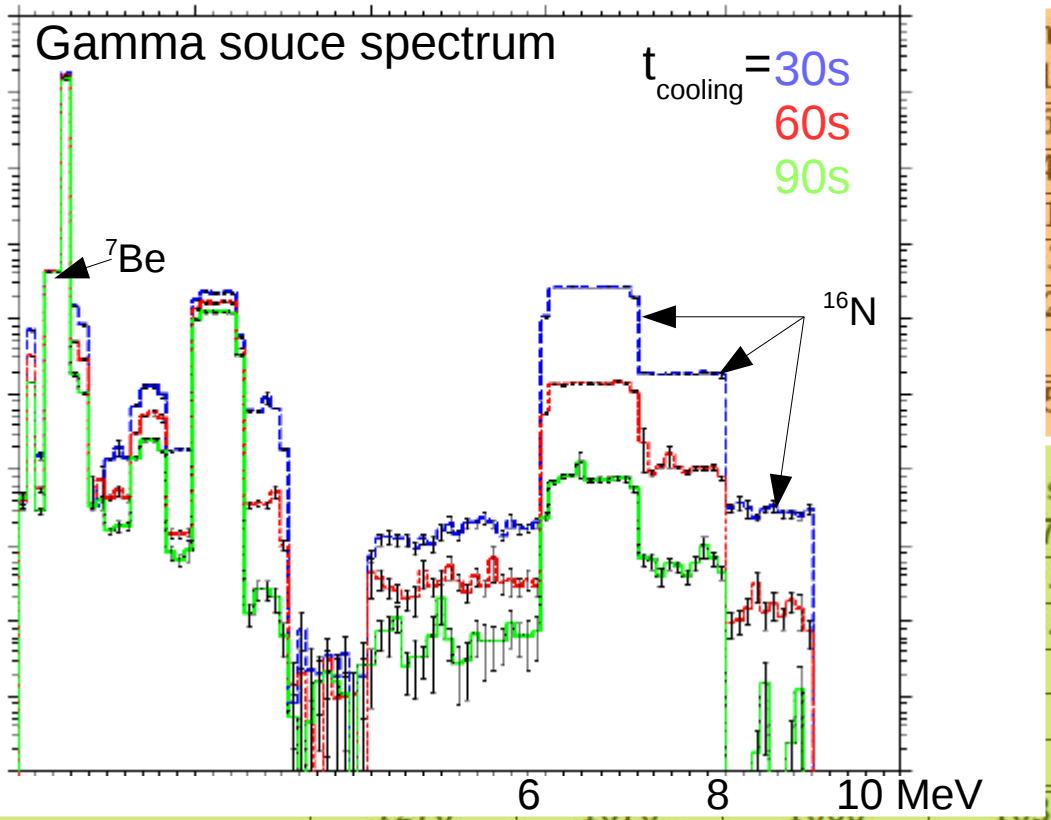
- The first few minutes, ^{16}N is the most problematic nuclide. At later times ^{7}Be

Inventory

Relevant for delay tank

Isotope	Half-life [s]
^{3}H	3.89E8
^{7}Be	4.61E6
^{11}C	1223
^{14}O	70.6
^{15}O	122
^{16}N	7.1
Total	

ne step [90s]	Time step 12 [120s]
621.3	621.3
445.1	445.1
1400	1377
38.5	28.7
2723	2297
0.8	0.04
5657	5180



Relevant for maintenance

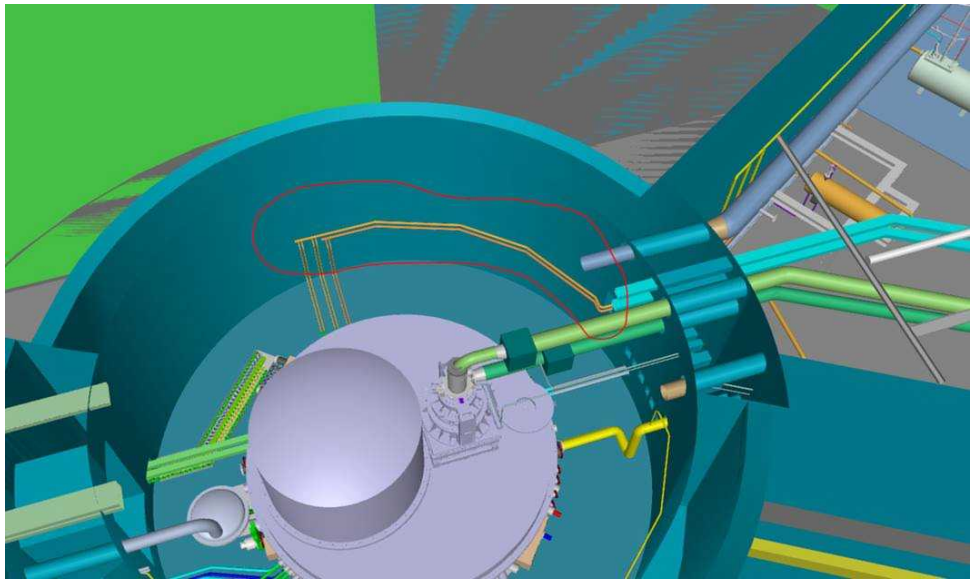
Isotope	Half-life [s]
^{3}H	3.89E8
^{7}Be	4.61E6
^{11}C	1223
^{14}O	70.6
^{15}O	122
Total	

step 7d]	Time step 17 [1y]
.6	587.3
.4	3.9
30	592

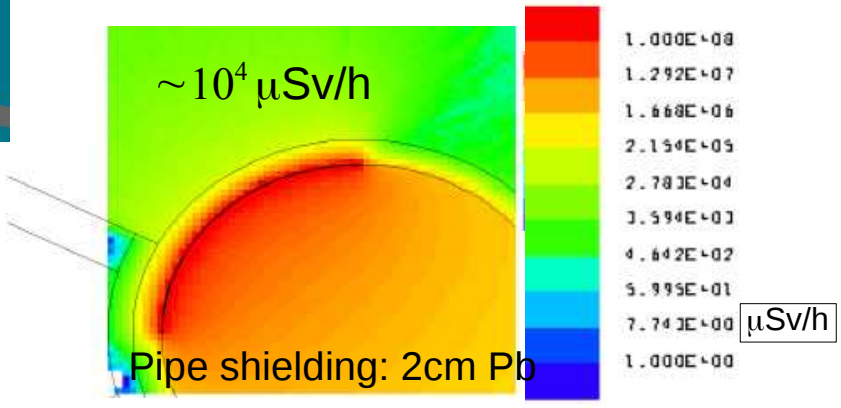
Activities in *Curie*. Only main contributers listed - “Total” includes all

- The first few minutes, ^{16}N is the most problematic nuclide. At later times ^{7}Be

Follow the water:
1 – Connection Cell



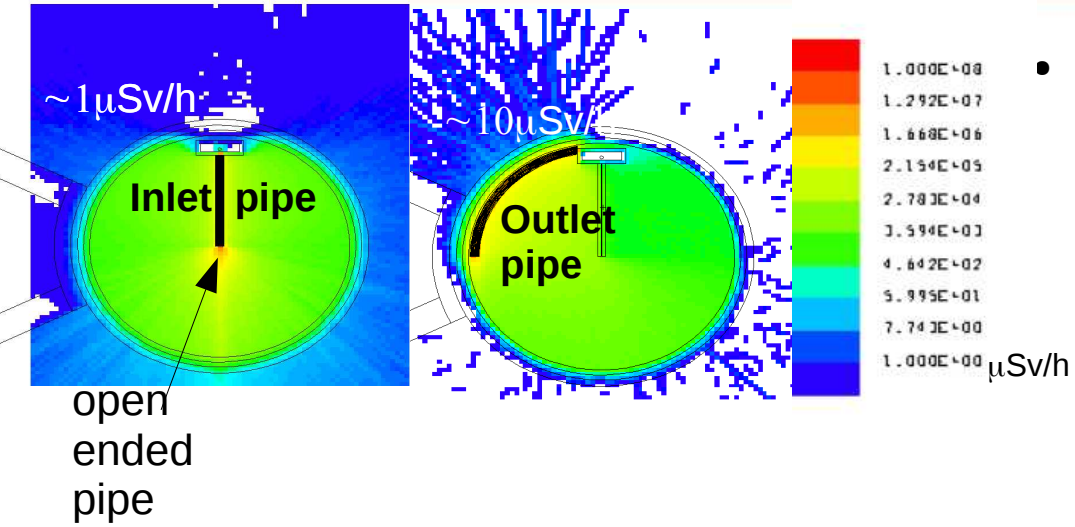
- Pipe at the thin instrument hall facing wall is problematic
- Impractical to shield
- Move <u>delay tanks to Connection Cell</u>

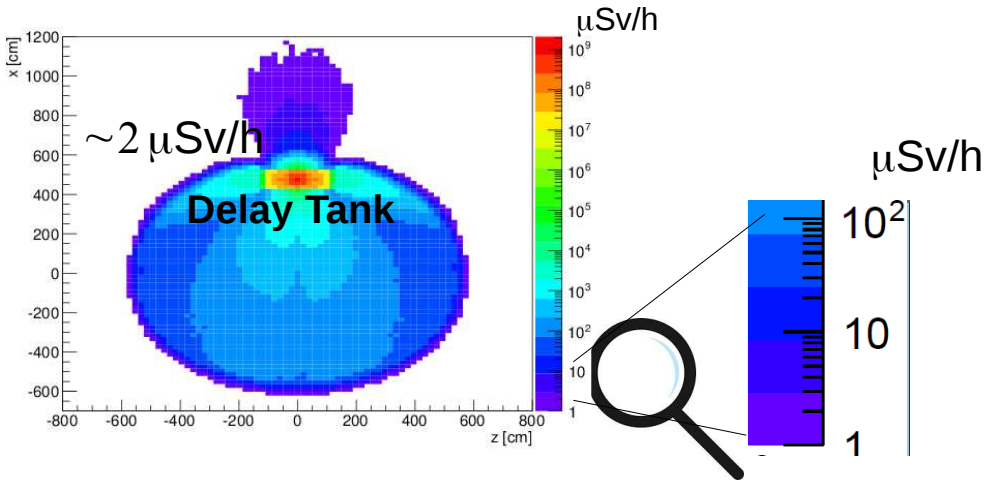


Conservative estimation:

- Overestimating water volume fraction,
- Underestimating cooling time

Shielding in Connection Cell





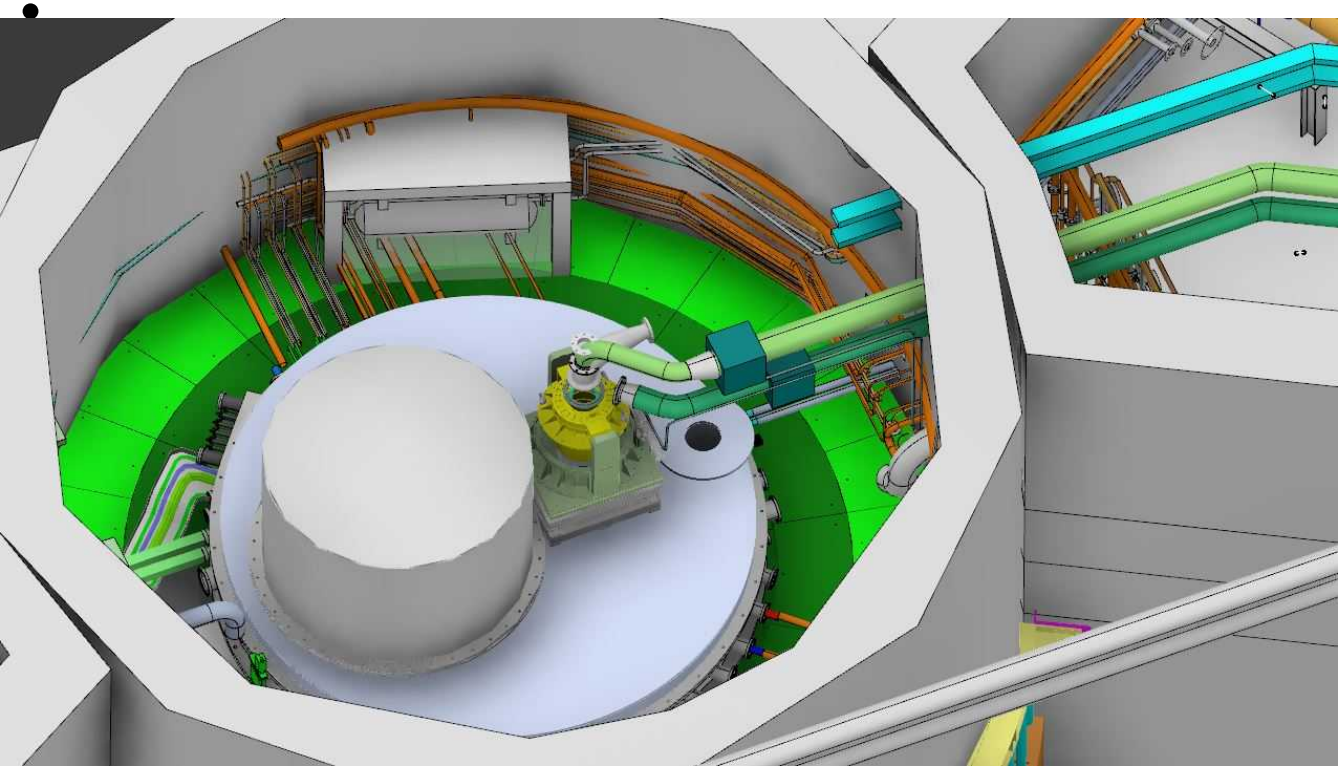
- Limit in instrument hall: 3μSv/h drives the shielding
  - ~12cm lead around Delay tank inlet pipe
  - ~18cm lead between delay tanks and instrument hall
  - 2cm lead around 90s delay tank outlet ←over conservative: Assumes ^{7}Be built up in water, rather than in filters.

Delay tanks – proposed solution

Solution

- Move (Thermal Moderator Cooling + Reflector Cooling) - Delay Tanks into Connection Cell
- Lead shielding
-

- Shield inlet pipes to delay tanks
- Avoid shielding of outlet pipes:
  - Use delay time 90 s
  - Remove conservatism in calculation for pipes inside connection cell



Delay tanks – proposed solution

EUROPEAN SPALLATION SOURCE

Issues/Risks

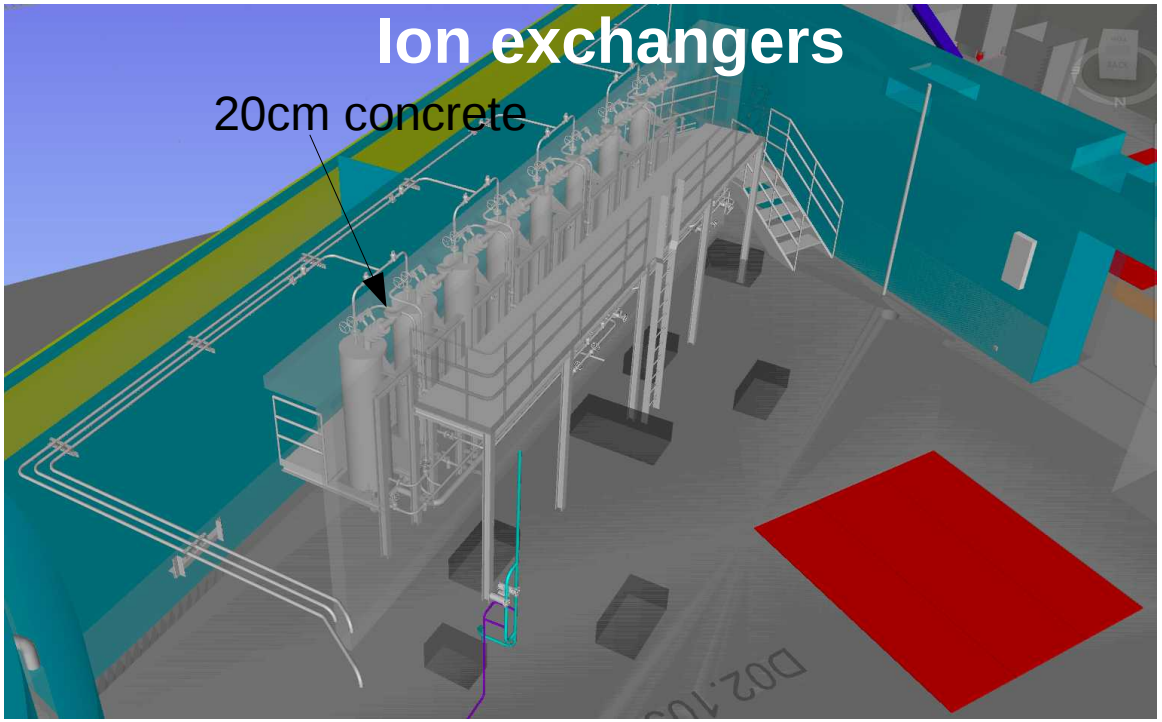
- Radiation resistance of electronics and drive unit
- Shielding of pipes within monolith vessel

Next steps

- Remove conservatism in calculations
- Alternative solution:
  Replace monolith shielding blocks with delay tanks
  Issue: High point in piping system could lead to H_2-pockets

Triangular rooms: maintenance

- After ~few hours, ^{7}Be in ion exchanger columns dominates
- Ion exchangers, situated behind 20cm concrete
- Optionally, unproblematic to add 10cm lead



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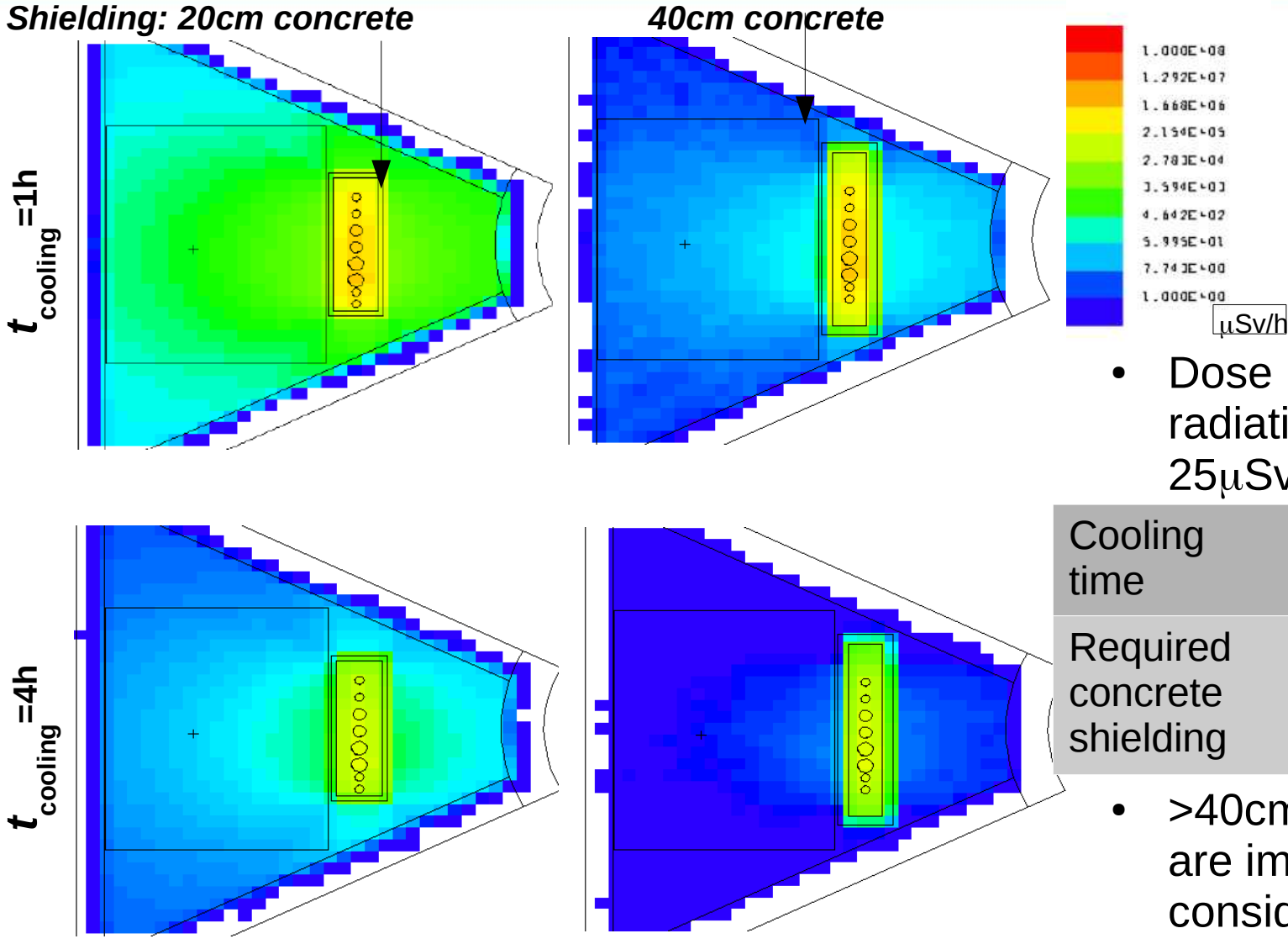
Triangular rooms: maintenance

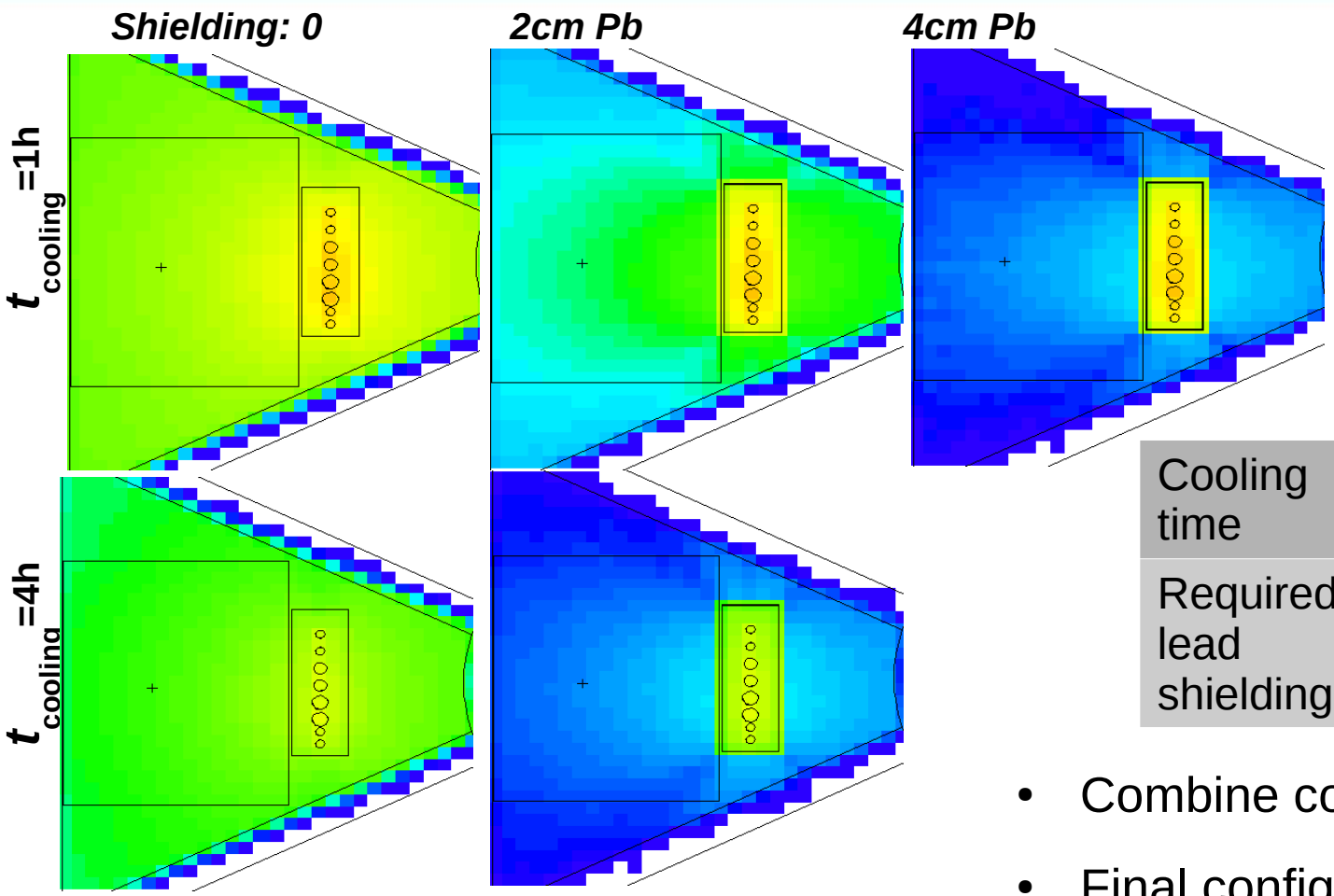


- Dose limit for radiation workers: 25µSv/h

Cooling time	1h	4h
Required concrete shielding	>40cm	40cm

- >40cm concrete walls are impractical => consider lead

Triangular rooms: maintenance



Cooling time	1h	4h
Required lead shielding	4cm	2cm

- Combine concrete and lead.
- Final configuration undecided

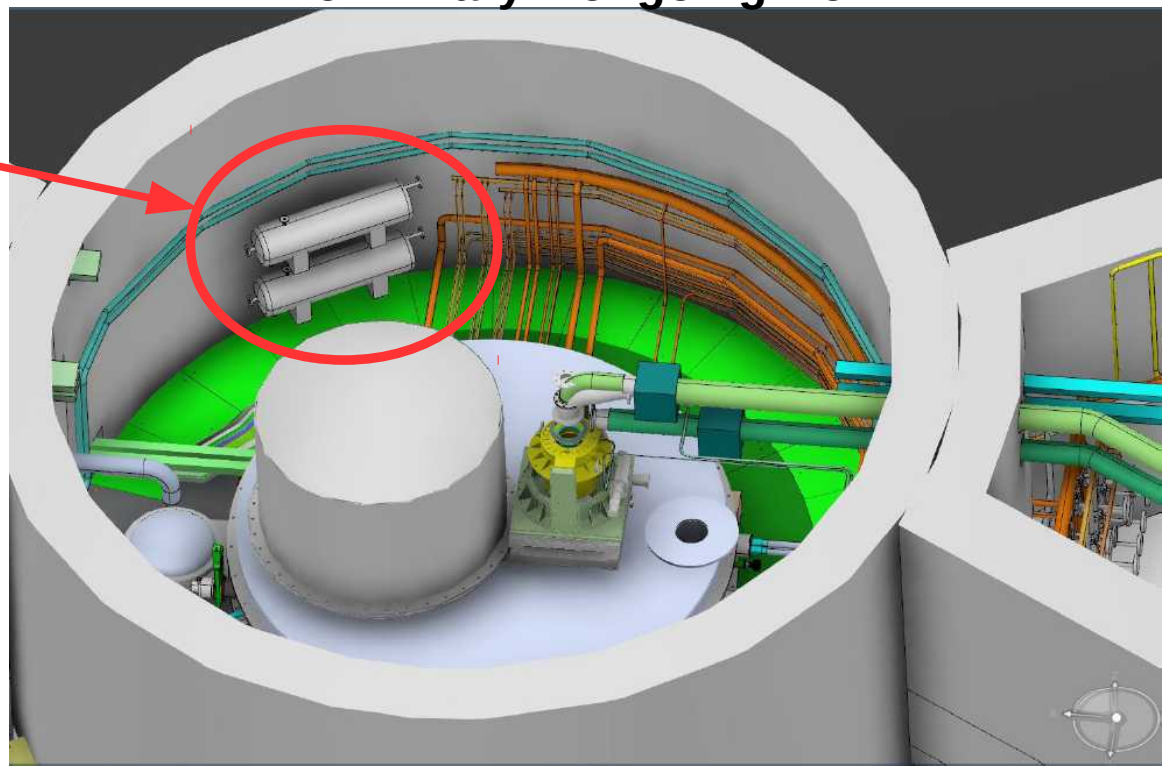
Conclusions

- The radiation from primary cooling water circuit is modeled in a simplified geometries.
- For each subsystem of the circuit the shielding needed to reach the required biological dose limits are calculated
- Under the assumption that the delay tank is moved into the connection cell, the results can be summarized as follows:
  - Delay tank inlet pipe Pb shielding : ~12cm
  - Delay tank Pb shielding : ~18cm
  - Delay tank outlet pipe Pb shielding : ~2cm [for 90s DT] ←over conservative. Likely not needed
  - Pipe Pb shielding in triangular rooms : ~0cm [for 90s DT]
  - Shielding in triangular rooms
    required for maintenance : 1 hour cooling: >40cm concrete / 4cm lead
    : 4 hour cooling: 40cm concrete / 2cm lead
- Final note: Ensure all contributers are accounted for: 3μSi/h / 25μSi/h is for everything

Next steps

- Engineering redesign:
  - Place delay tank in connection cell
  - Add shielding to pipes and ion exchanger
- Neutronics:
  - Remove over-conservatism: model 7Be as (mostly) filtered in ion exchanger
  - Model electronics in connection cell
  - Refine neutronics models according to updated engineering

Preliminary – ongoing work



Backup slides

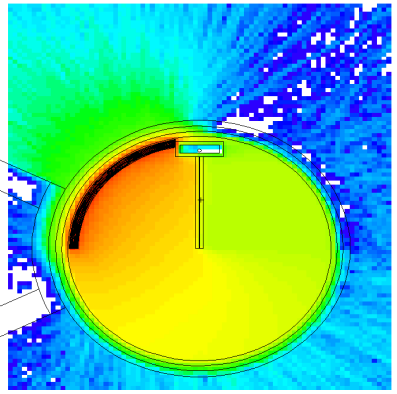
4 – delay tank outlet pipe - extra

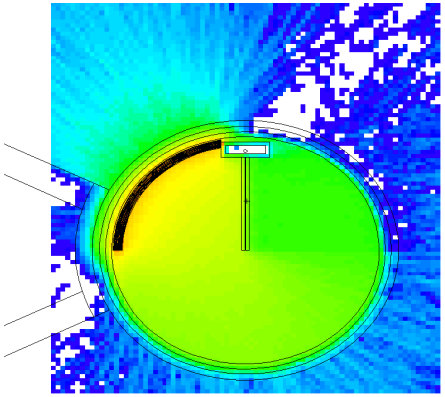
Pipe shielding: 0

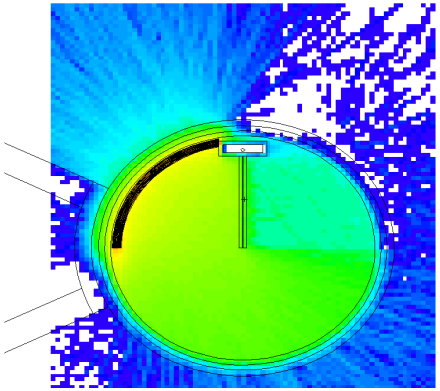
Pipe shielding: 2cm Pb

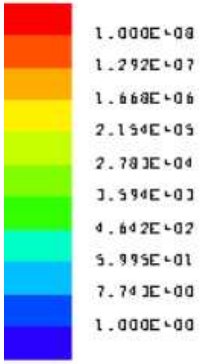
Pipe shielding: 4cm Pb

t=30s







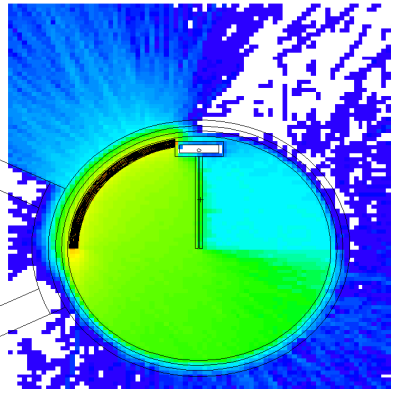


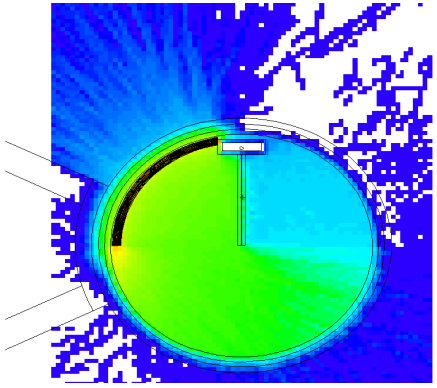
Pipe shielding: 6cm

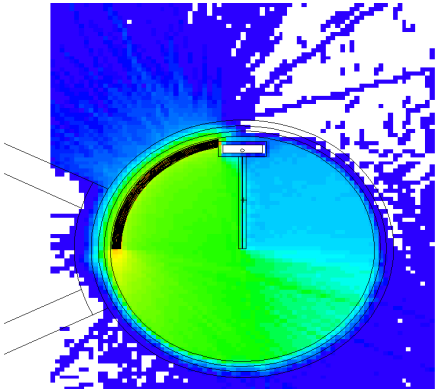
Pipe shielding: 8cm Pb

Pipe shielding: 10cm Pb

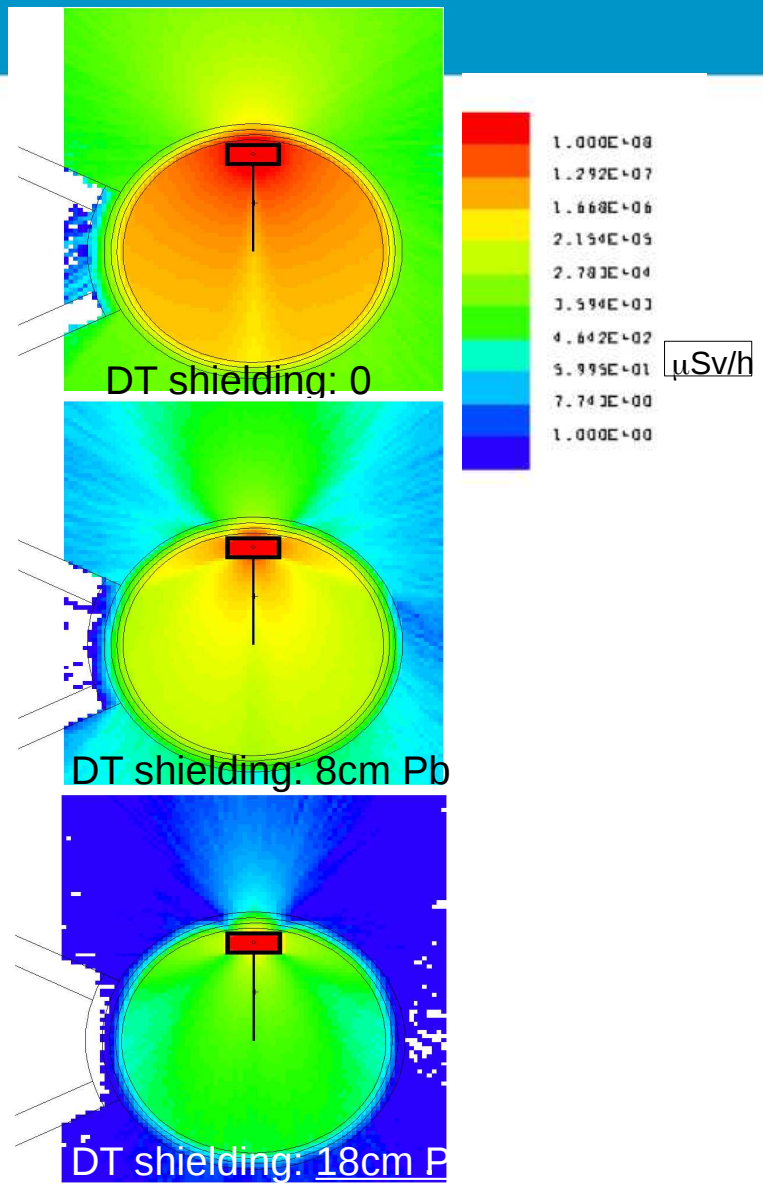
t=30s





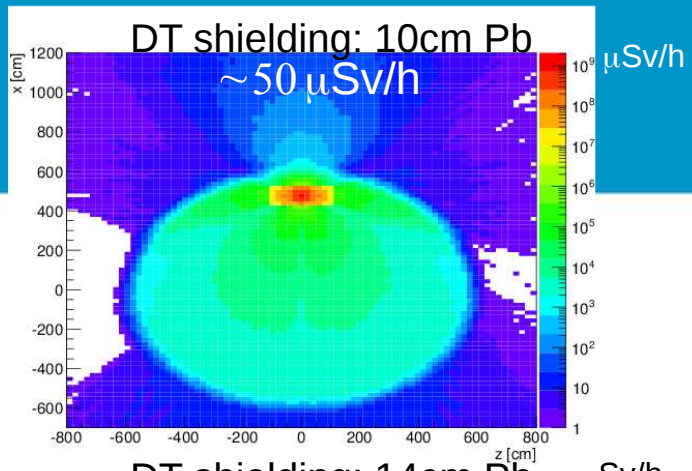


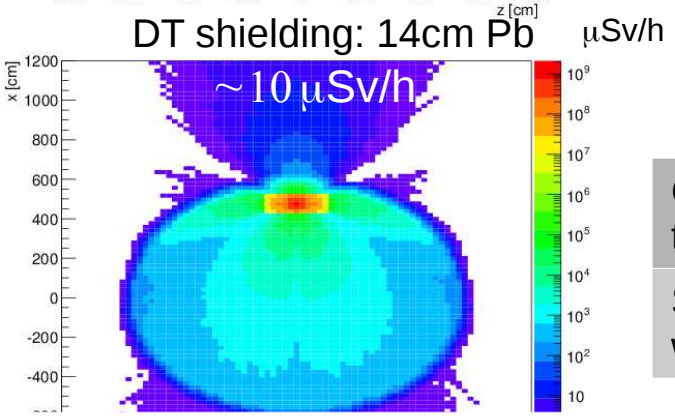
2 – delay tanks

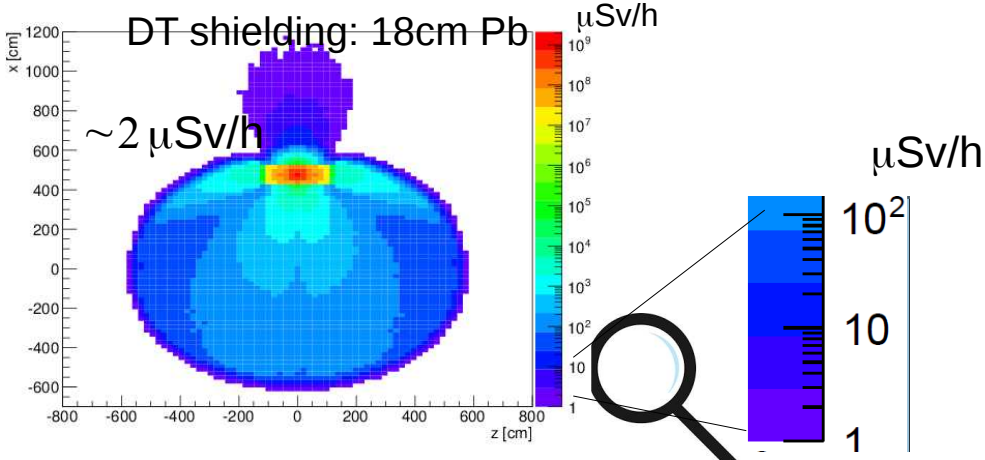


- Alterntive approach : *Full source term* at $t_{cooling}$=0 is placed in the delay tank
- Conservative: neglects delay, water volume fraction
- The shielding on the room-facing size, may be relaxed – from a solid angle consideration ~ the dose level in the instrument hall is ~$(1m/10m)^2$ lower, corresponding to ~4cm lead

2 – delay tanks





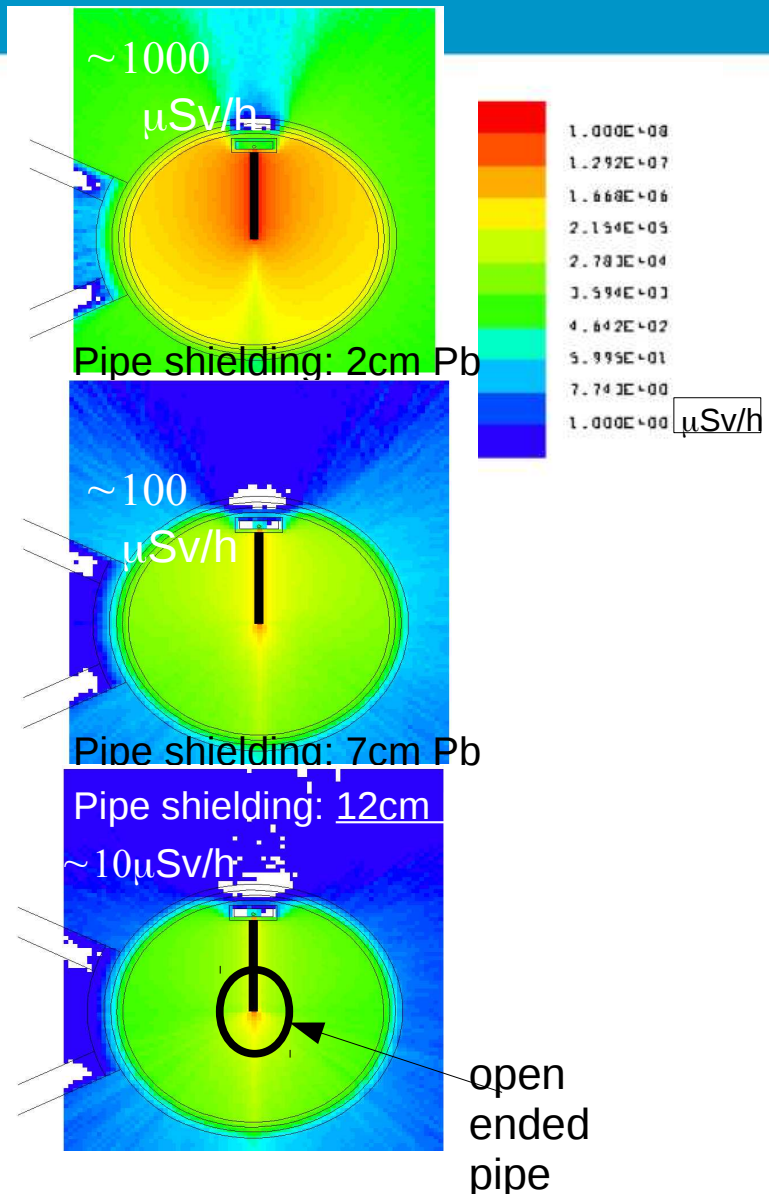


- 9L of water in the moderator. Exhaust speed 0.6L/s => average cooling time at exit: 7.5s.
- 5m vertical + 5m horizontal: 5s
- Starting at $t_{cooling}$: 7.5s+5s = 13s, the delay tank is modeled:

Cooling time [s]	13	16	19	22	25	28	31	34	37
Source weight [%]	12	12	12	12	12	12	12	12	4

- I.e. CINDER'90 is re-run, to prepare source definitions. For each shielding geometry, 9 separate MCNP simulations are performed and the resulting dose-rate maps added
- ~18cm lead needed to reach dose-level requirements in the instrument hall

3 – delay tank inlet pipe

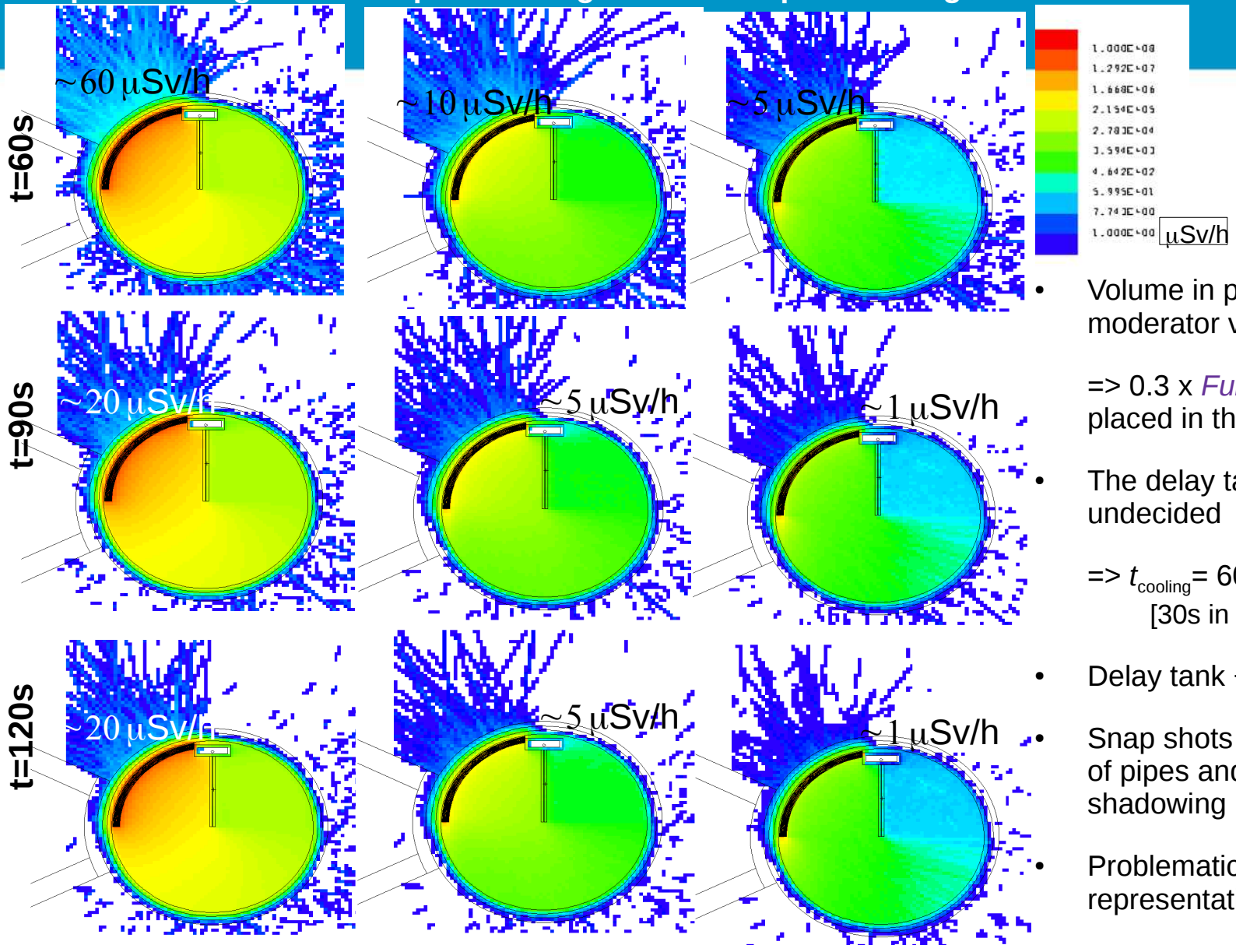


- Volume in pipe ~1/6 moderator volume

  => 1/6 x *Full source term* at $t_{cooling}$=0 is placed in the pipe

- Conservative: no cooling
- ~12cm lead needed to ensure sufficiently low dose levels in the instrument hall

4 – delay tank outlet pipe



- Volume in pipe ~0.3 x moderator volume

  => 0.3 x *Full source term* is placed in the pipe

- The delay tank size is undecided

  => $t_{cooling}$= 60s, 90s, 120s
  [30s in backup slide]

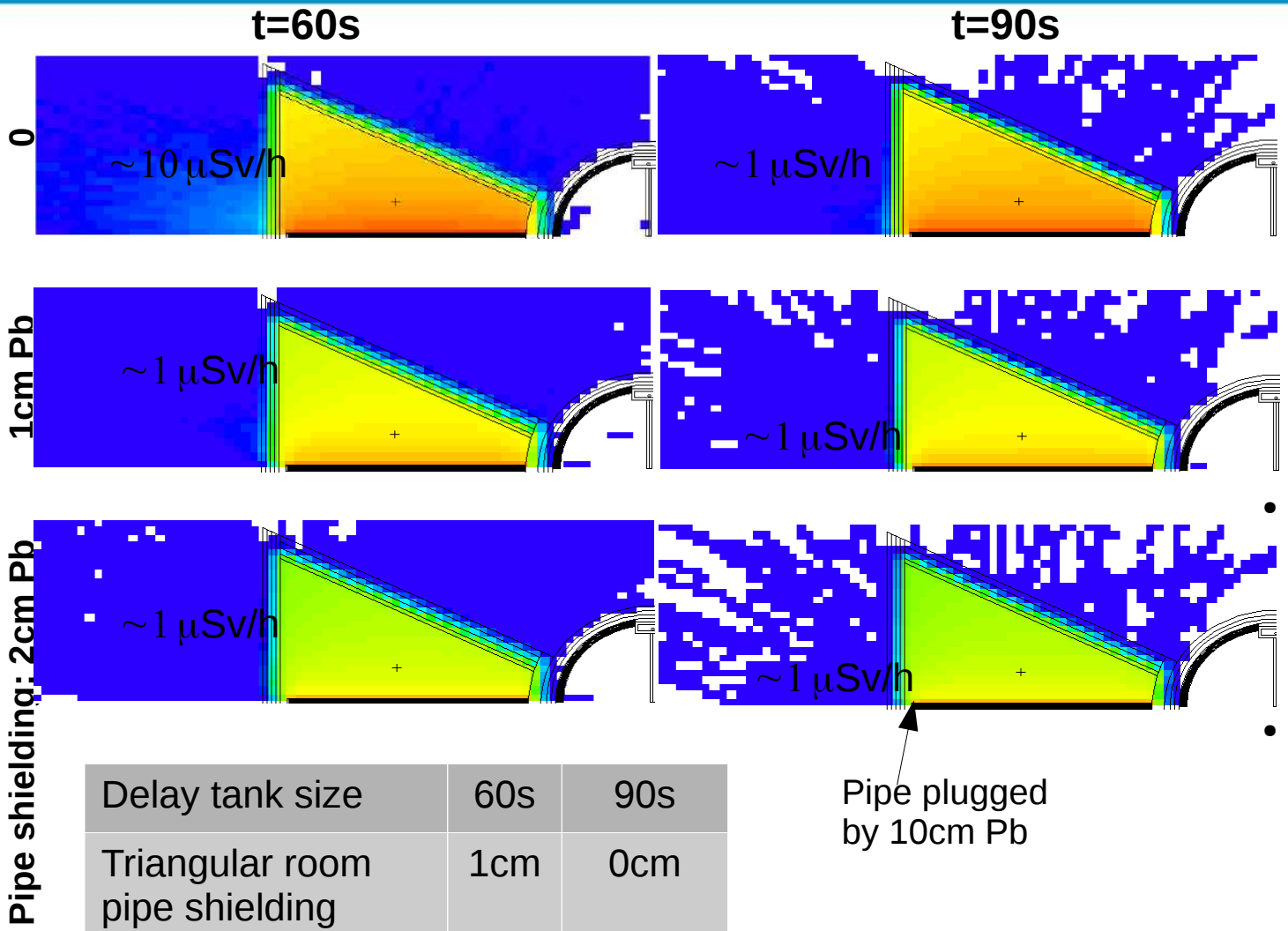
- Delay tank + pipe in place
- Snap shots are in the plane of pipes and delay tank => shadowing is over estimated
- Problematic region representative

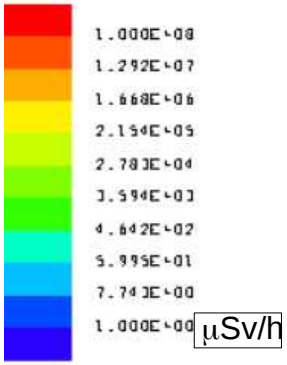
4 – delay tank outlet pipe

- Shielding requirements on the outlet pipe depend on the size of the delay tank

Delay tank size	30s	60s	90s	120s
Outlet pipe shielding	10cm	4cm	2cm	2cm

5 – triangular rooms: pipes



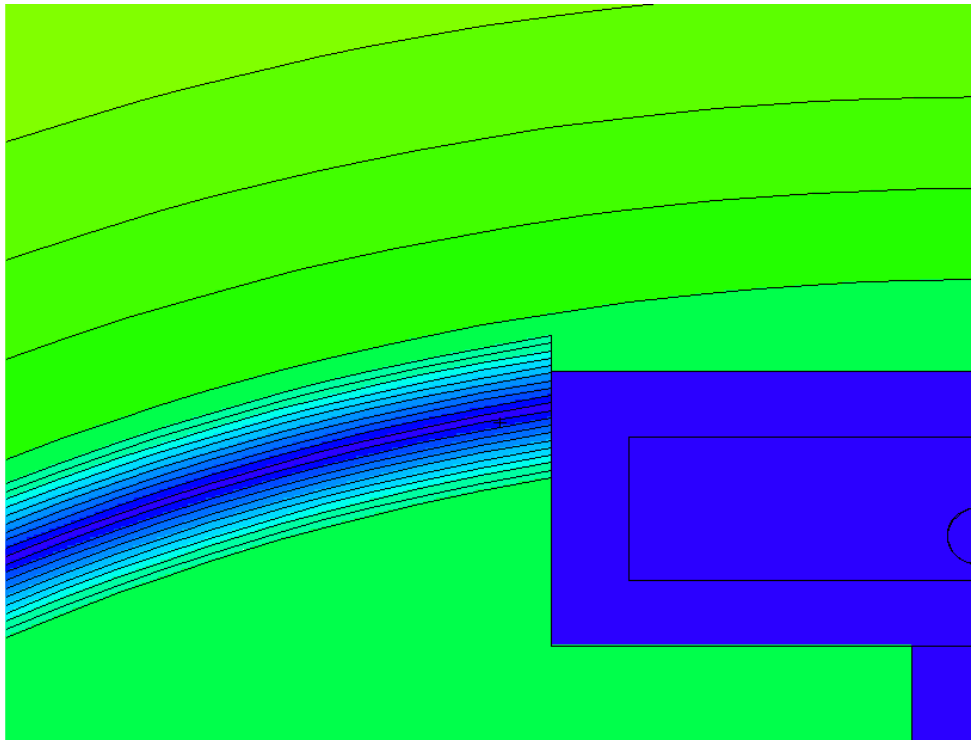


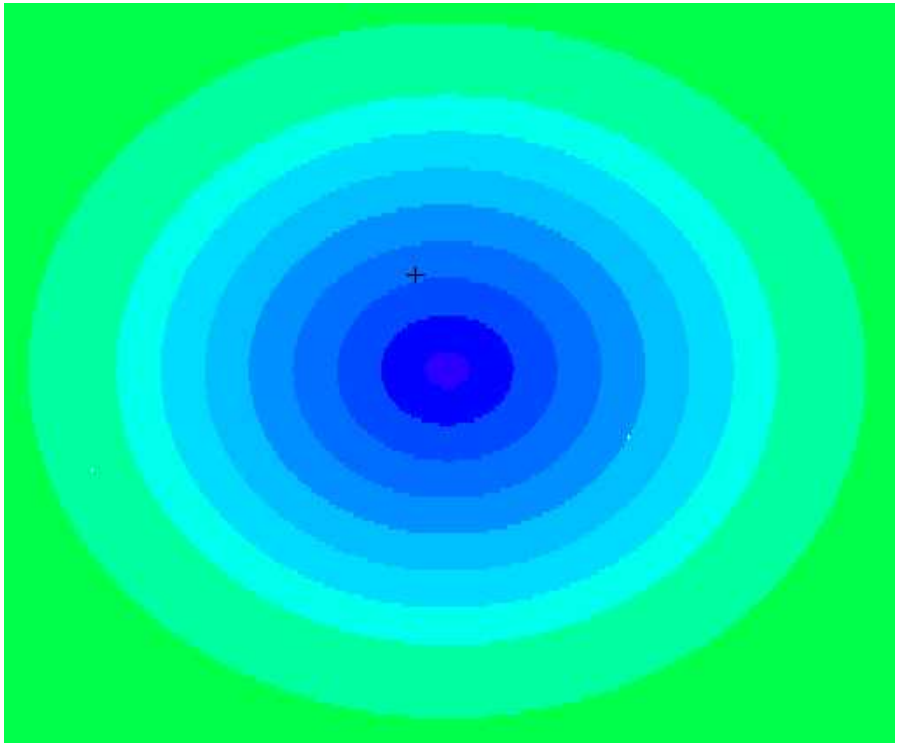
Delay tank size	60s	90s
Triangular room pipe shielding	1cm	0cm

- Volume in 30m pipe corresponds to the moderator volume
- Approach: Place *Full source term* at $t_{cooling}$ =60s, 90s is placed in a pipe in the triangular room

Importance biasing

- Importance doubled every 2cm in lead and 25cm in concrete





Zoom in of delay tank and outlet pipe[left] and pipe cross-section [right].
Colored by gamma importance.