Radiation challenges of primary cooling return water at the ESS

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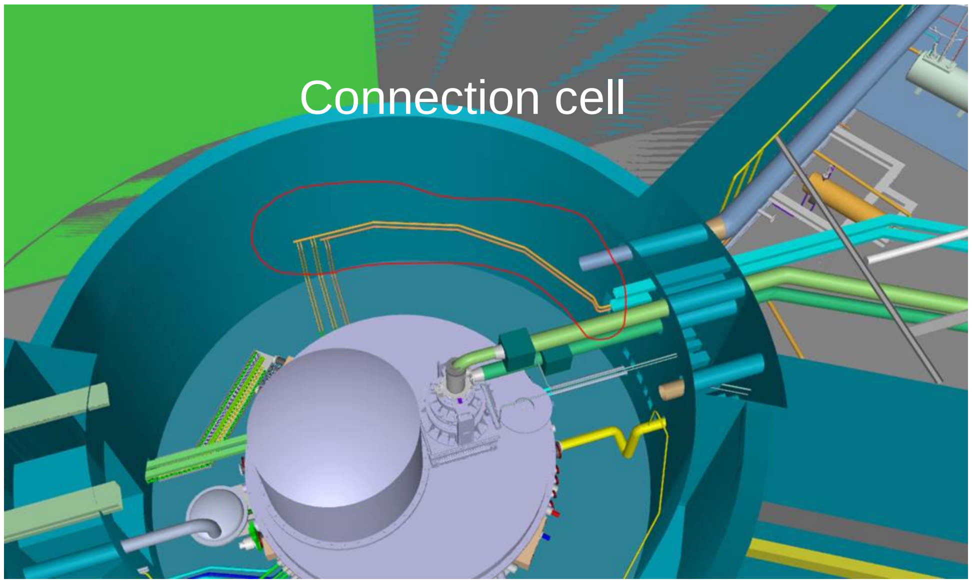
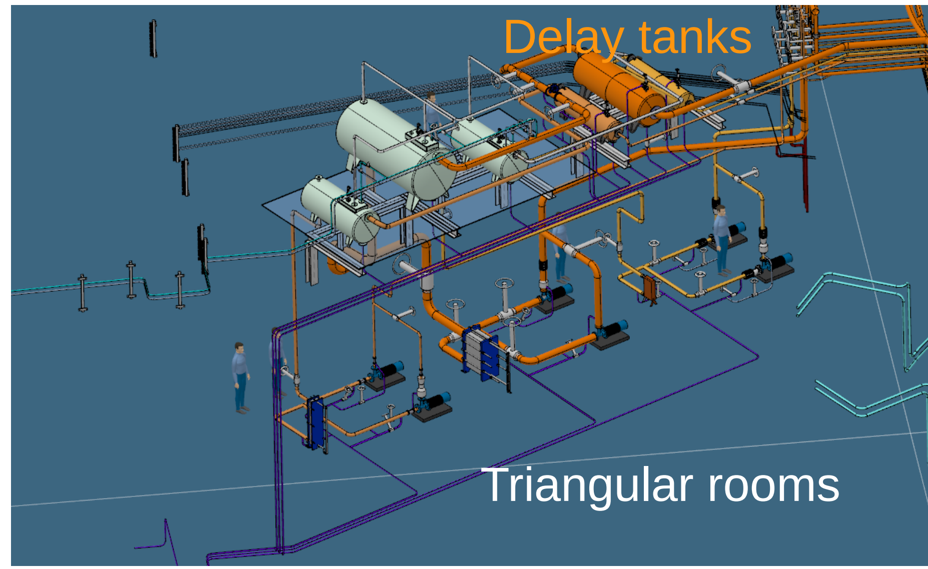
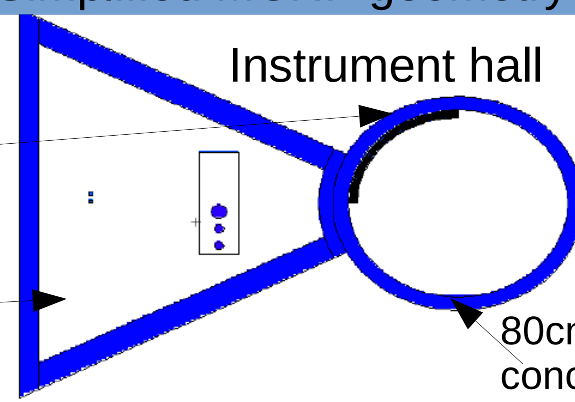
Water circuit overview





Simplified MCNP geometry

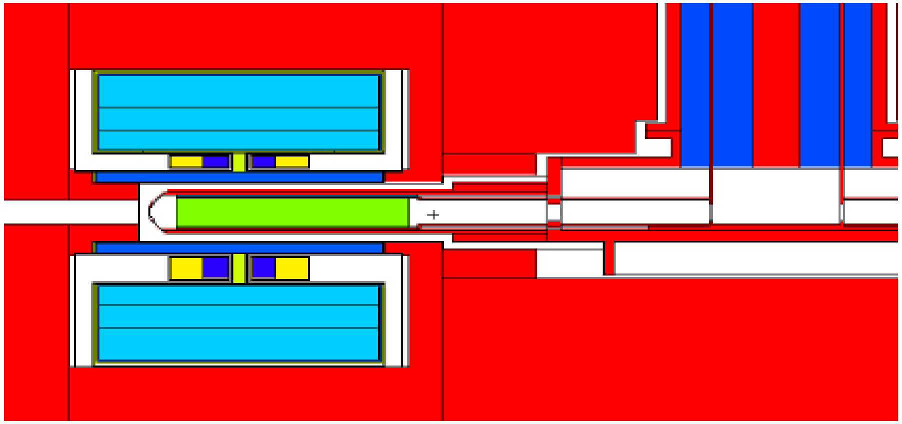


During operations, requirements on the biological dose-rate are:

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

Source term

- *p* at 2GeV



- 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)

Methods

EUROPEAN SPALLATION SOURCE

- 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*
- *<u>Full source term</u> 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] [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

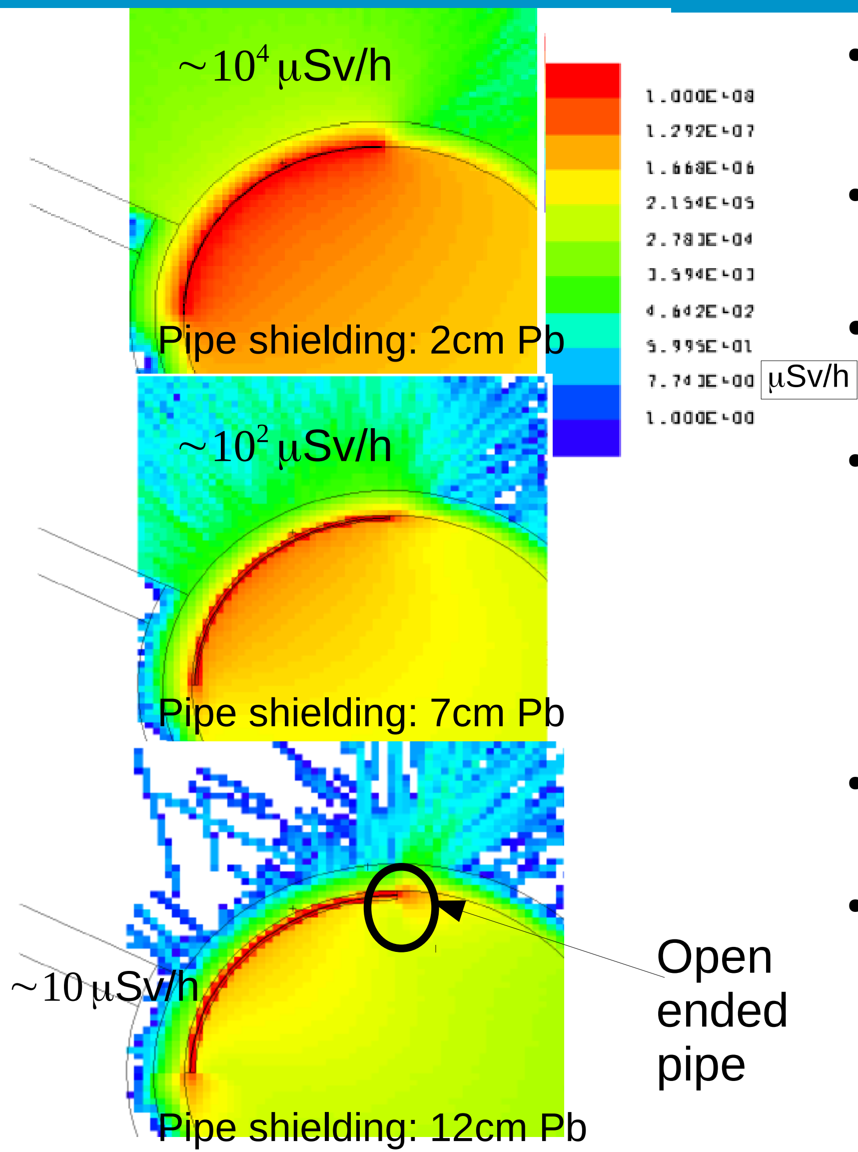
Isotope	Half-life [s]	Decay mode	Time step 13 [1h]	Time step 14 [4h]	Time step 15 [1d]	Time step 16 [7d]	Time step 17 [1y]
^{3}H	3.89E8	β	621.3	621.3	621.2	620.6	587.3
^{7}Be	4.61E6	EC$\beta + \gamma[477keV]$	444.9	444.2	439.4	406.4	3.9
^{11}C	1223	β	191.6				
^{14}O	70.6	$\beta + \gamma[2.3MeV]$					
^{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
- Strategy:
  - follow the water from the reflector and through the various subsystems of the water circuit.
  - At each component, adjust shielding to reach requirements for biological dose level

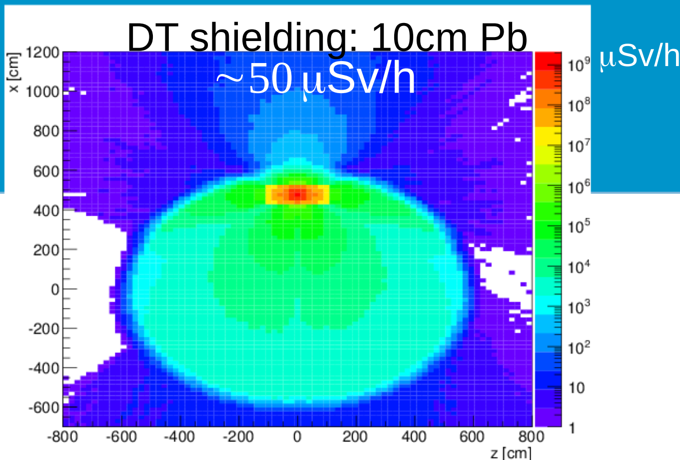
Follow the water:
1 – connection cell

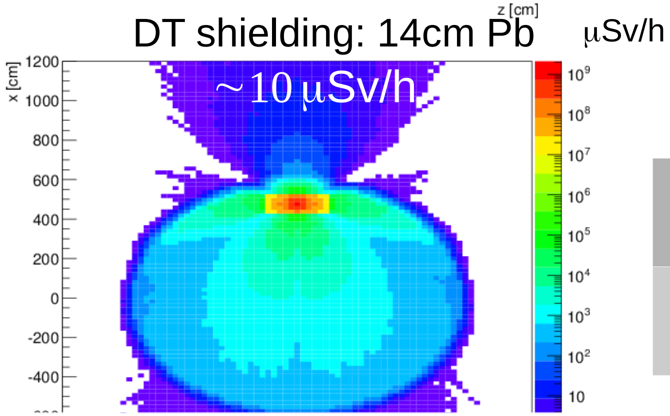
EUROPEAN SPALLATION SOURCE

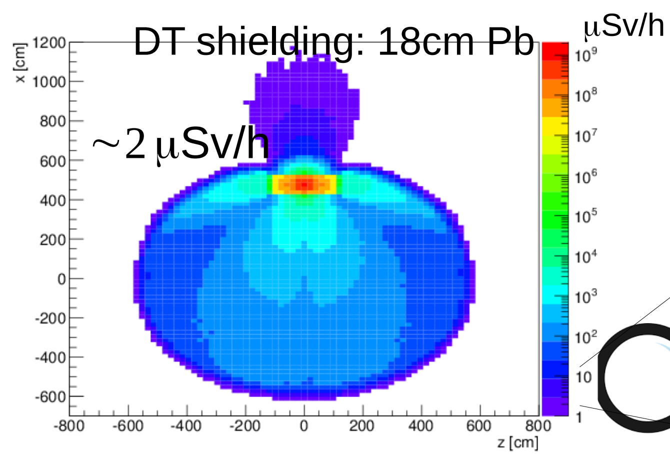


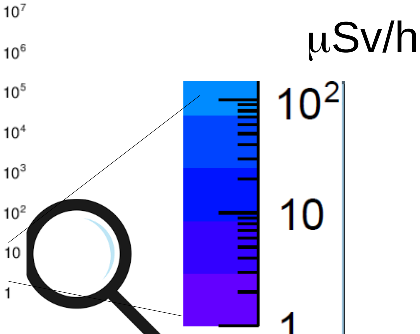
- At ~few seconds of cooling, the dominant isotope is ^{16}N with $T_{½}$ = 7s and 6.1MeV gamma
- The pipe constitute a serious challenge, due to it's vicinity to the instrument hall
- *Full source term* at $t_{cooling}$=0 is placed in the pipe following the circumference
- Over-conservative since:
  - The volume of 15m of pipe is only half the moderator volume => only a fraction of the full source term is at play
  - The flow speed is 2m/s => cooling time is ~5s to ~10s
- Nevertheless, the pipe at the thin instrument hall facing wall is problematic =>
- Work is ongoing to re-route / shield the pipe

2 – delay tanks







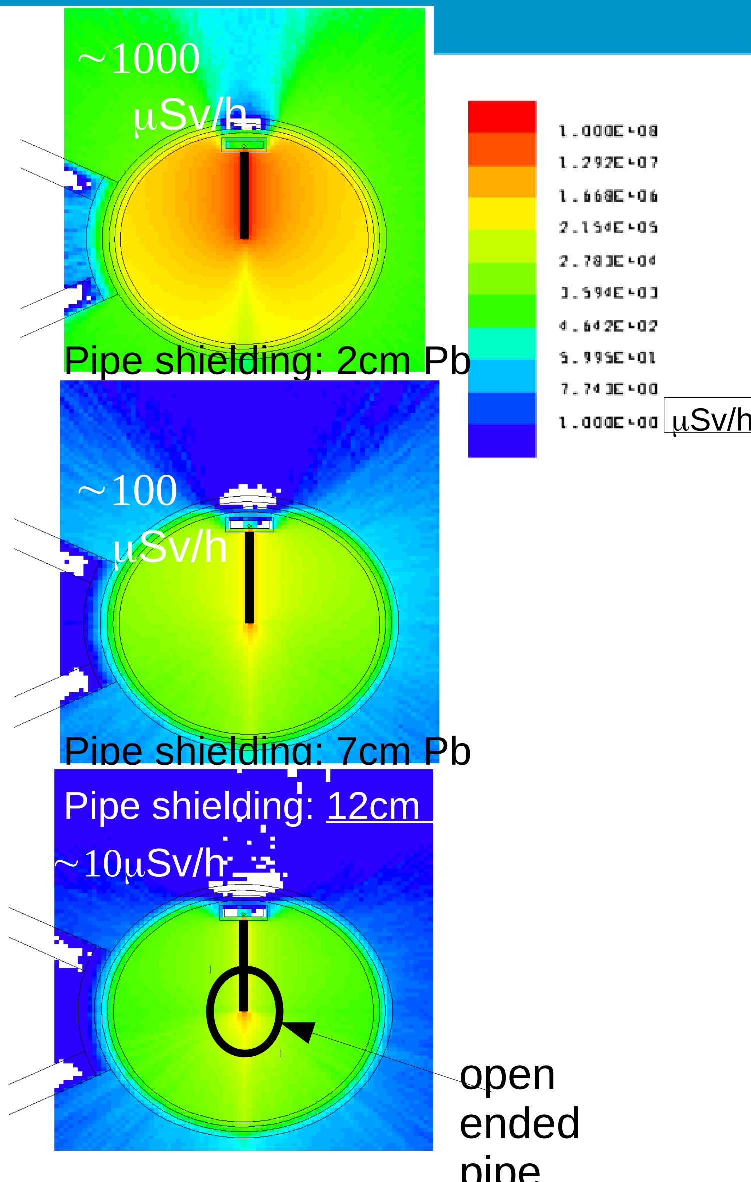


- 9L of water in the moderator. Exhaust speed 0.6L/s => average cooling time at exit: 7.5s.
- 5m vertical + 5m horizontal: 5s
- Starting at $t_{cooling}$: 7.5s+5s = 13s, the delay tank is modeled:

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 – piping in the connections cell

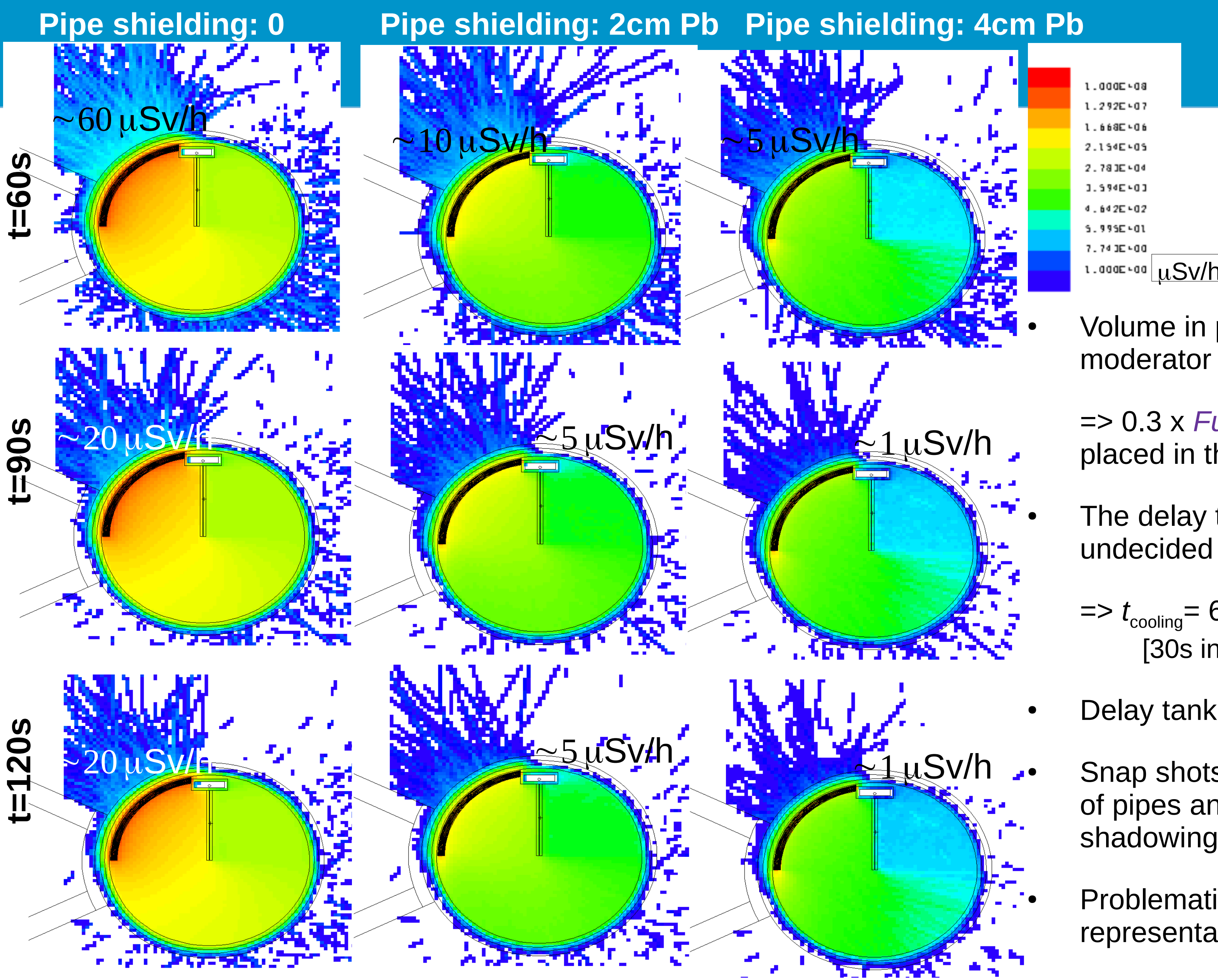


- Volume in pipe ~1/6 moderator volume

  => 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

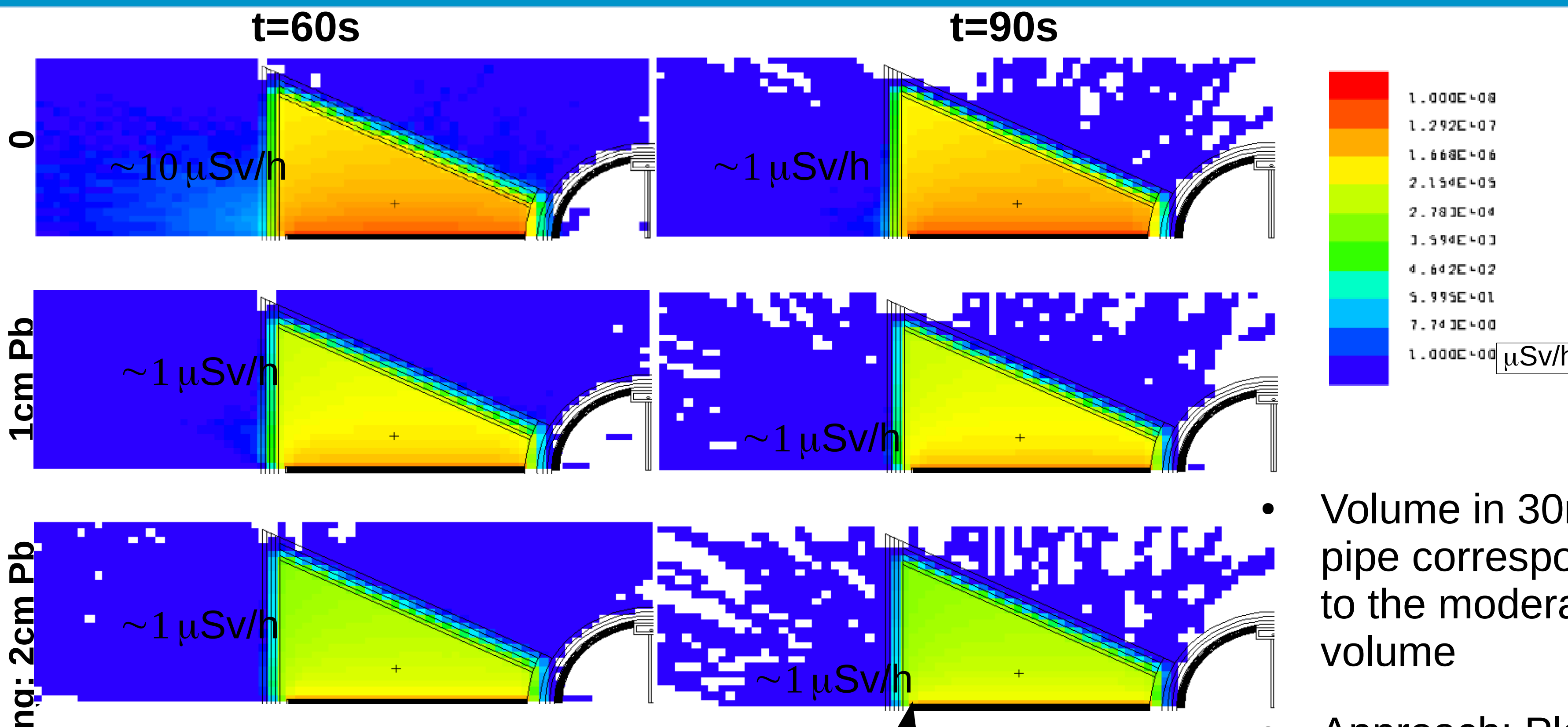
4 – delay tank outlet pipe

- 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

- New baseline

5 – triangular rooms: pipes



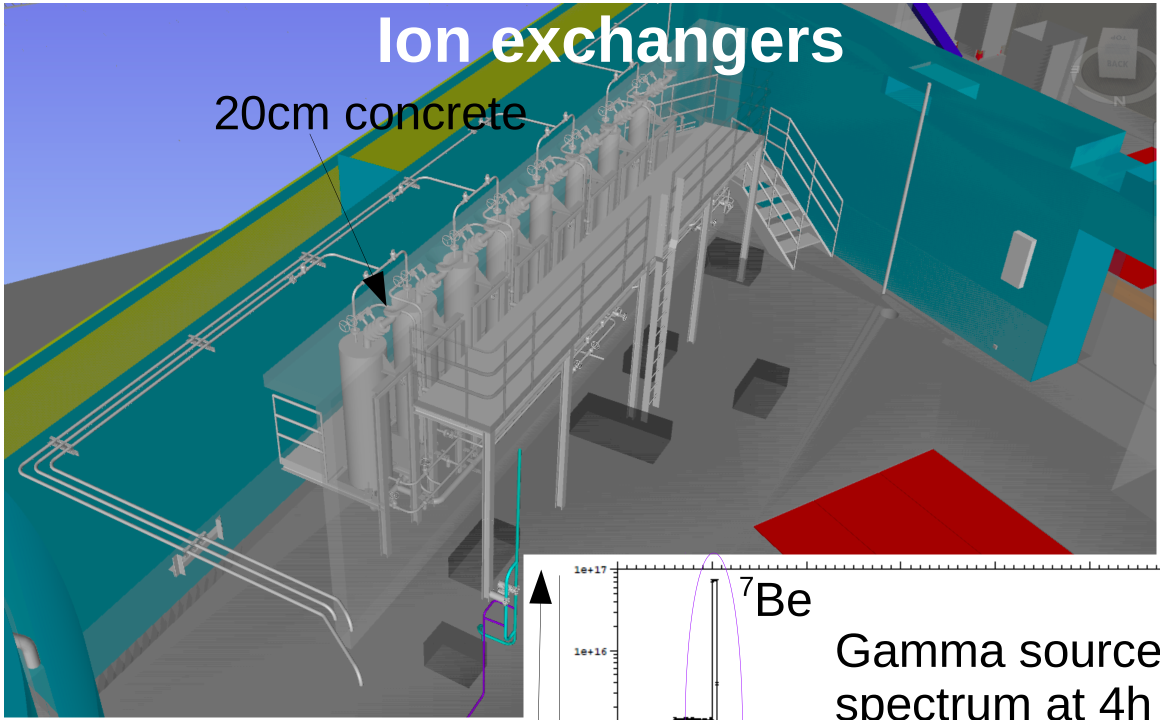
Pipe plugged by 10cm Pb

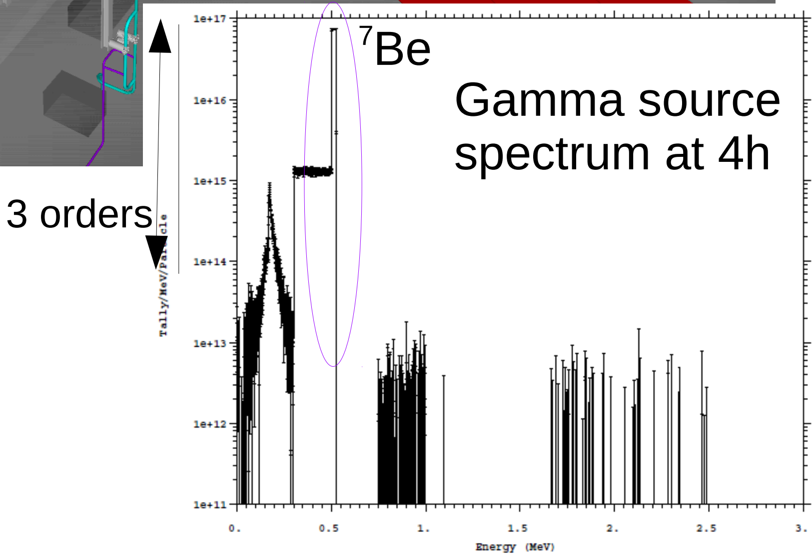
Delay tank size	60s	90s
Triangular room pipe shielding	1cm	0cm

- 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

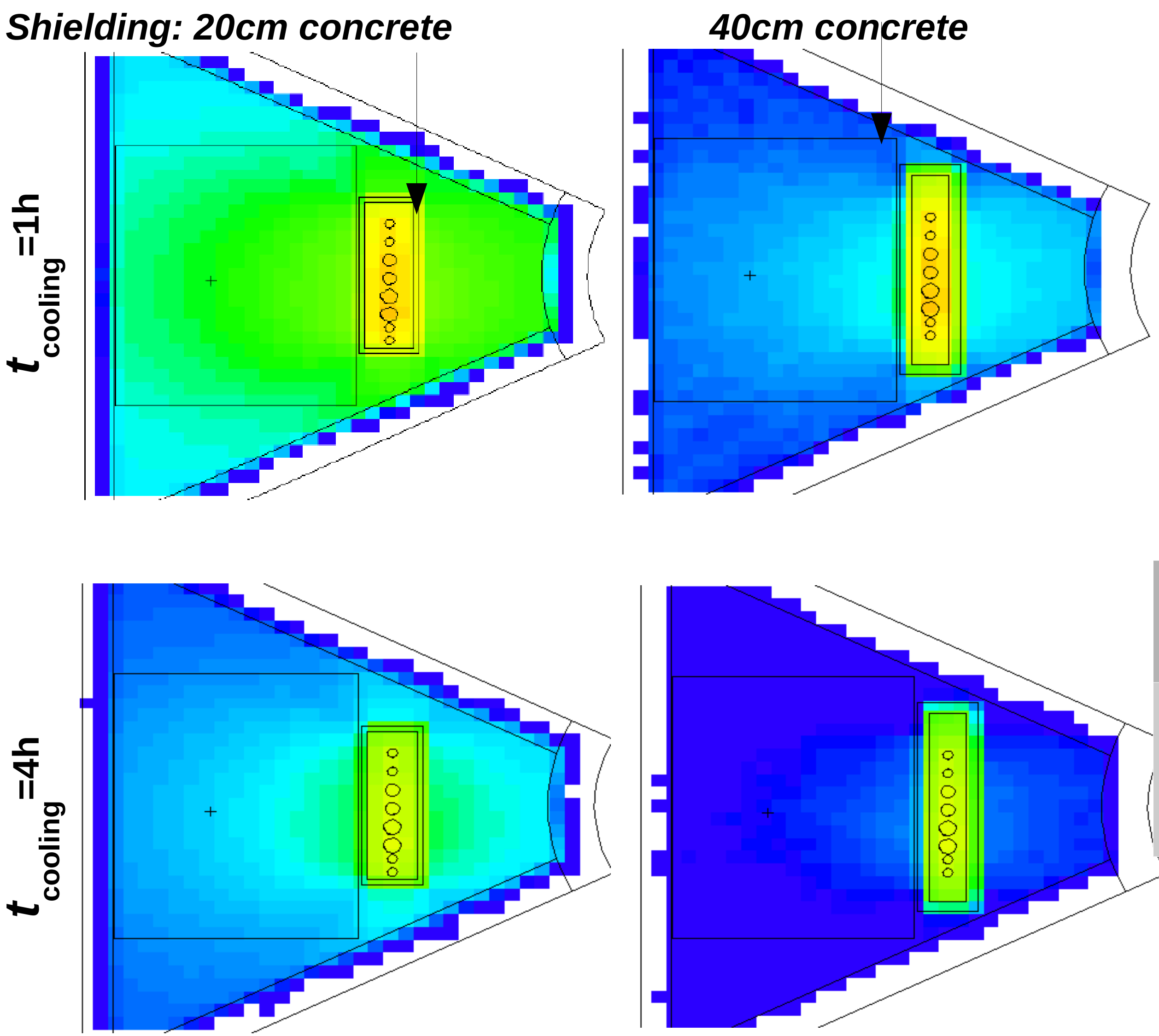
6 – triangular rooms: maintenance

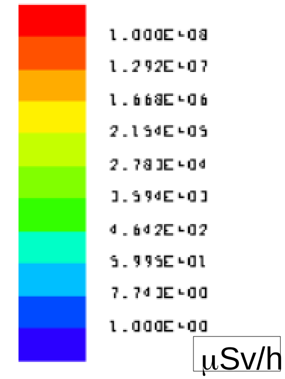
- Cooling time expected prior to entering the triangular rooms for maintenance
- At 1-4 hours, ^{7}Be dominant
- ^{7}Be should not be dissolved in water, but filtered in ion exchangers situated behind 20cm concrete [baseline]
- Approach: *Full source term* at $t_{cooling}$ =1h, 4h in placed in rectangular concrete shielding box





6 – triangular rooms: maintenance



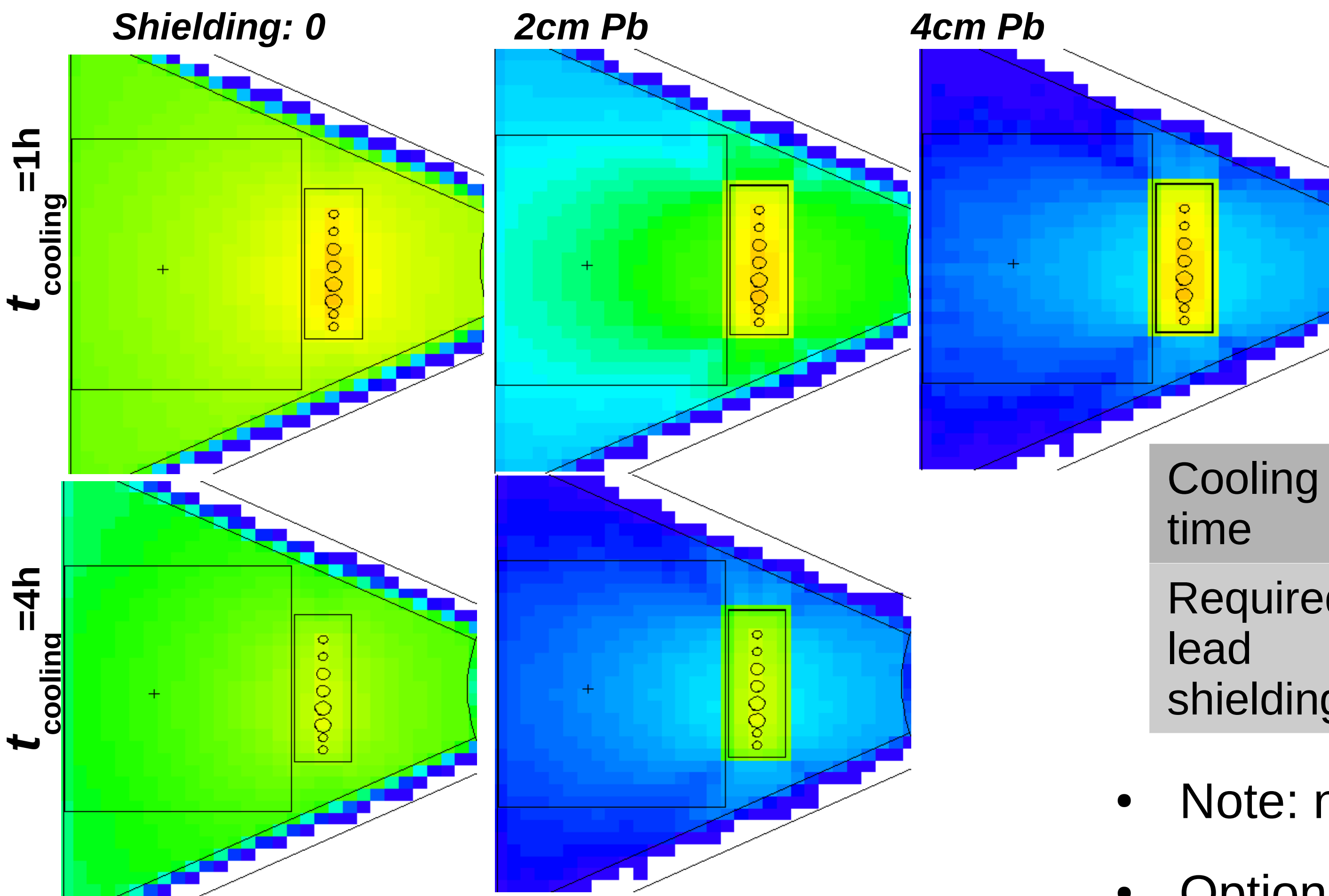


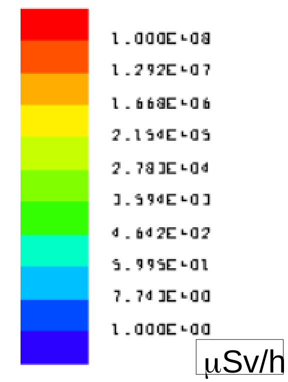
- Dose limit for radiation workers: 25µSv/h

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

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

6 – triangular rooms: maintenance





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

- Note: no concrete in place
- Option: combine concrete and lead

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]
  - 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

- It is recommend that:
  - Delay is moved in connection cell. Size 90s, At least 18cm of lead toward instrument hall
  - The ion exchanger walls be made as thick as feasible, optionally lead mounted
  - Pipes in the connection cell are encapsulated in lead: 12cm for delay tank inlet, 2cm for outlet

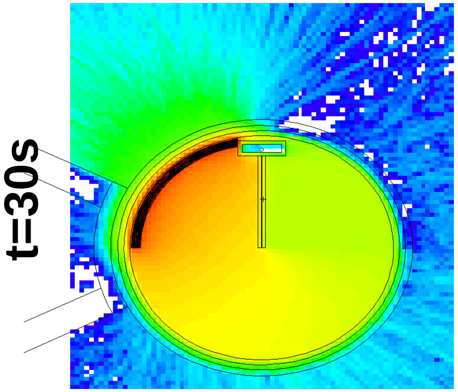
- Final note: Ensure all contributers are accounted for: 3μSi/h / 25μSi/h is for everything

Backup slides

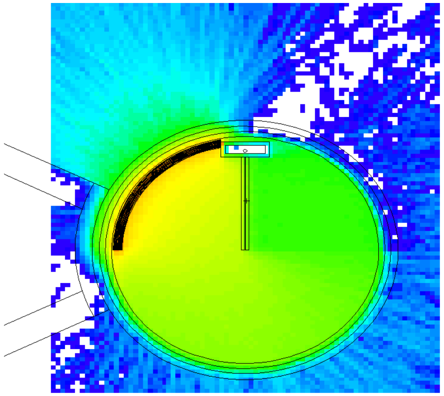
4 – delay tank outlet pipe - extra

t=30s

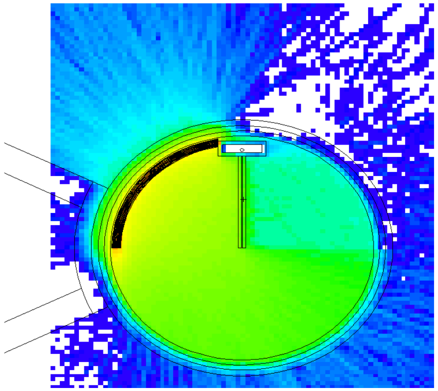
Pipe shielding: 0

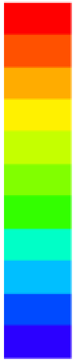


Pipe shielding: 2cm Pb



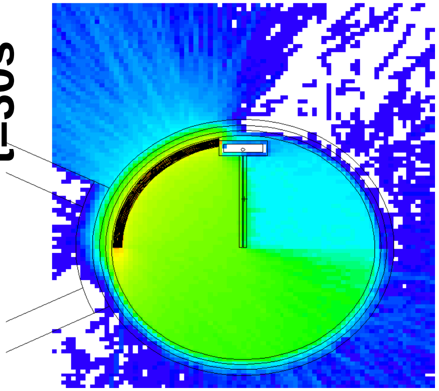
Pipe shielding: 4cm Pb



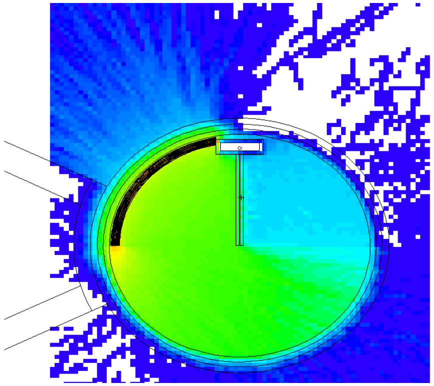


t=30s

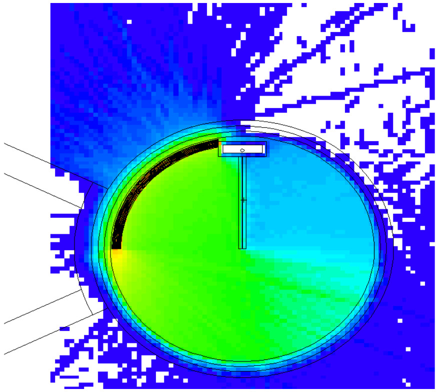
Pipe shielding: 6cm



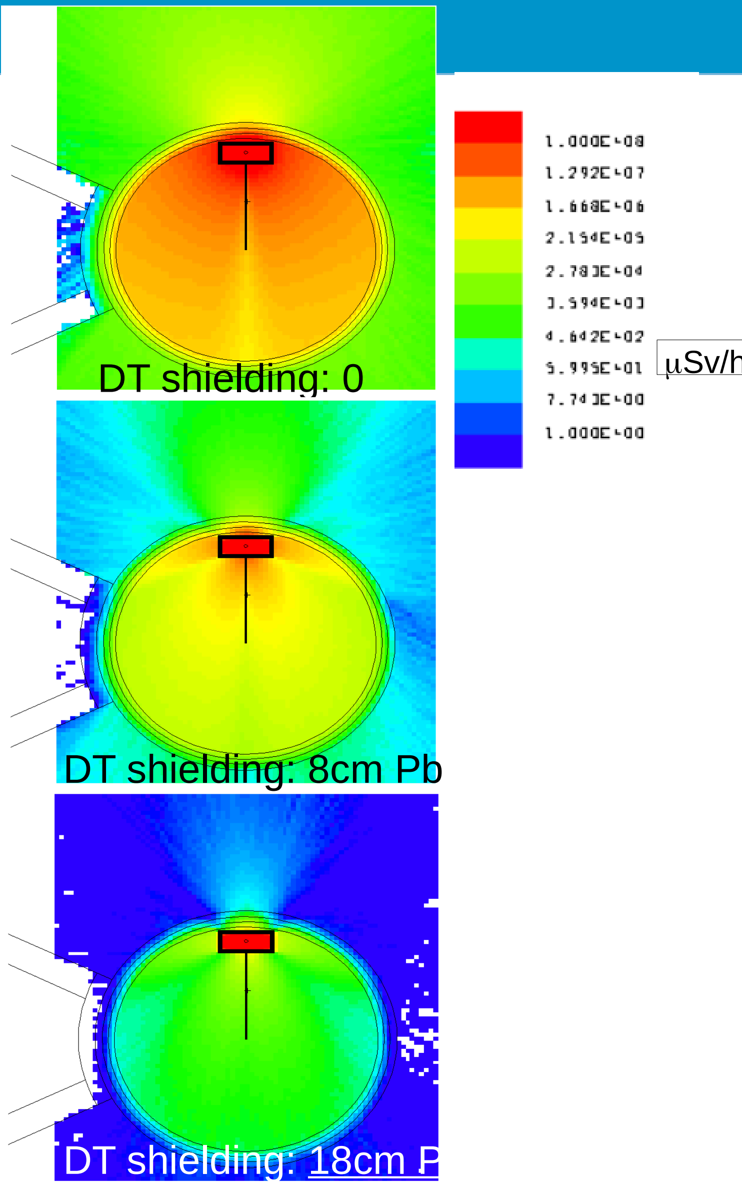
Pipe shielding: 8cm Pb



Pipe shielding: 10cm Pb



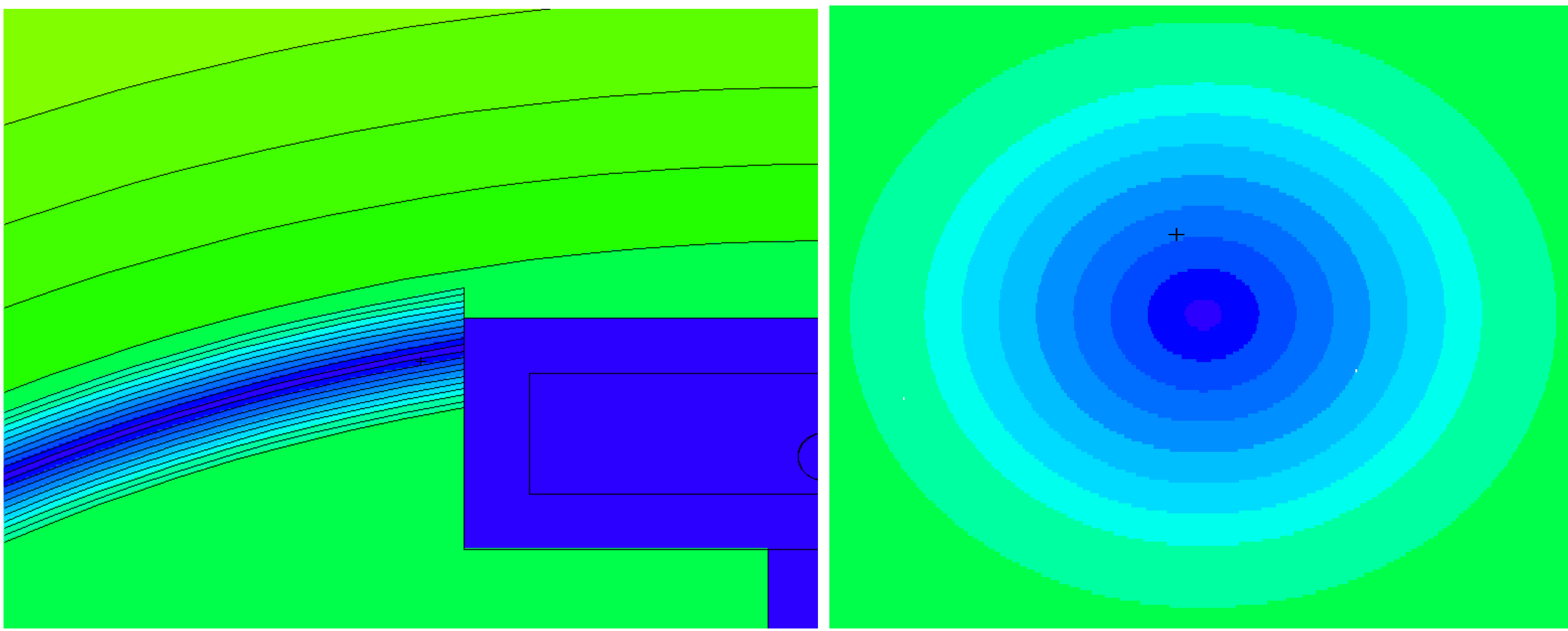
2 – delay tanks



- <u>Alterntive approach :</u> *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

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.