

SPES Project

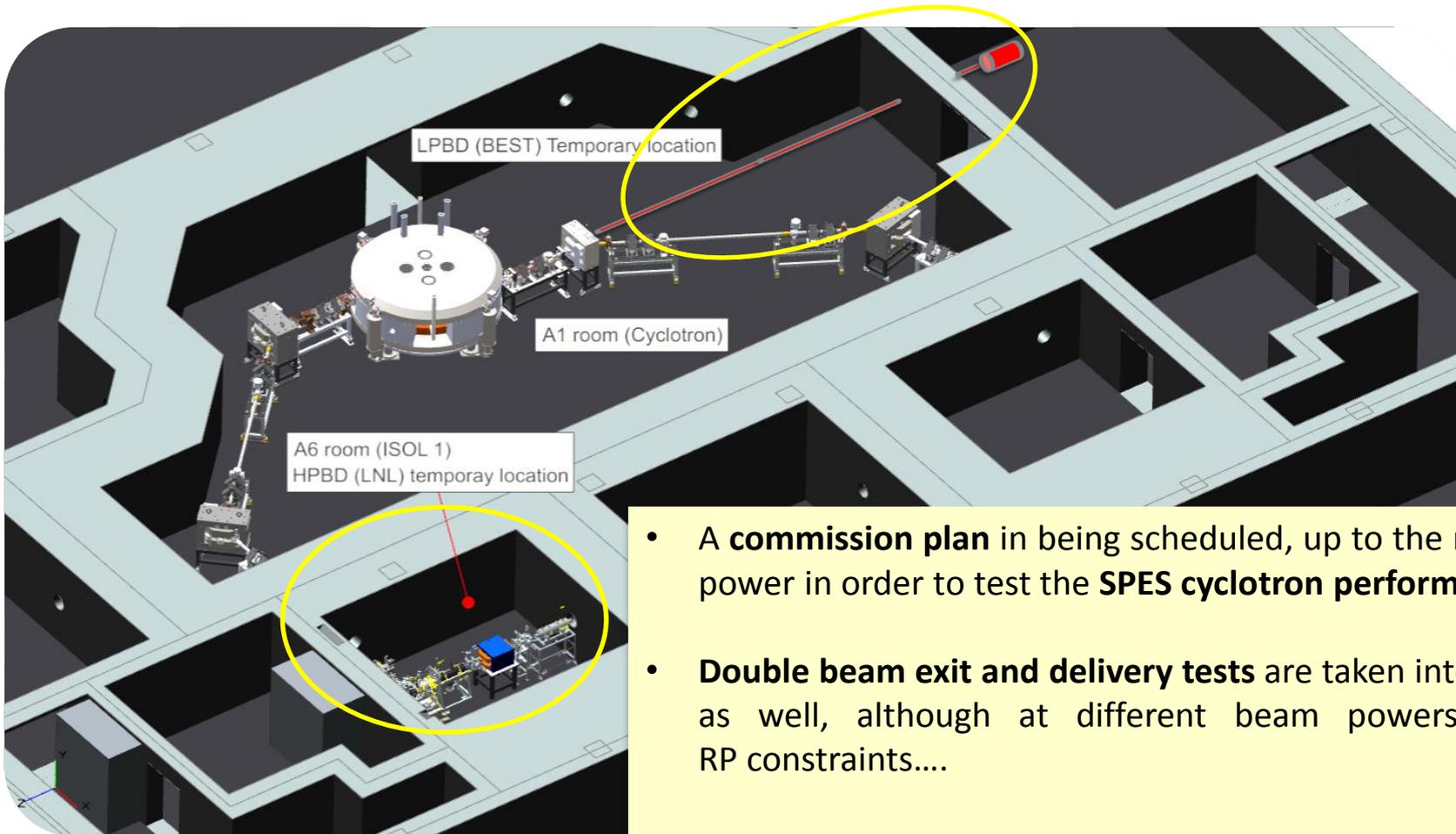


SPES High Power Beam Dump (BD) design status

J. Esposito on behalf of SPES BD Working Group

SPES Safety TAC meeting
Laboratori Nazionali di Legnaro
NFN LNL
July 23, 2015

The SPES cyclotron commissioning plan

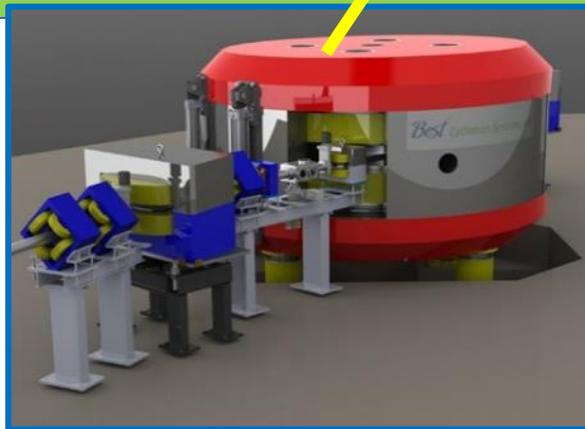
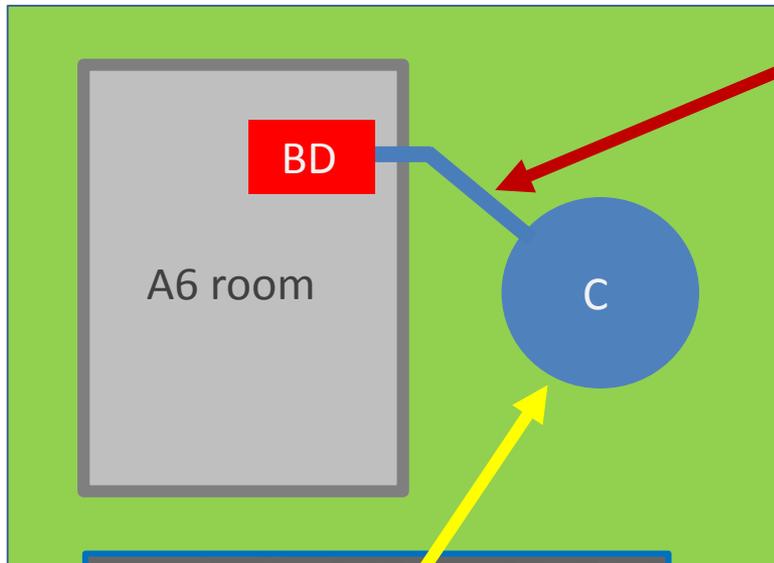


- A **commission plan** is being scheduled, up to the maximum power in order to test the **SPES cyclotron performance**.
- **Double beam exit and delivery tests** are taken into account as well, although at different beam powers due to RP constraints....
- A **double Beam Dump system** is anyway needed....
 - a) **LPBD** (BEST company provided) temporarily installed in A2 room ($< \sim 0.5$ kW tests)
 - b) **HPBD** (LNL) installed in A6 room (up to max power)

The need of a BD system for SPES cyclotron commissioning....

A proper Beam Dump system, able to stop the full power is needed for the scheduled SPES cyclotron commissioning.

The BD has to guarantee the **full power heat removal** in a **safety way** fulfilling all the **BD specs** as well as **Radio Protection (RP) limits**

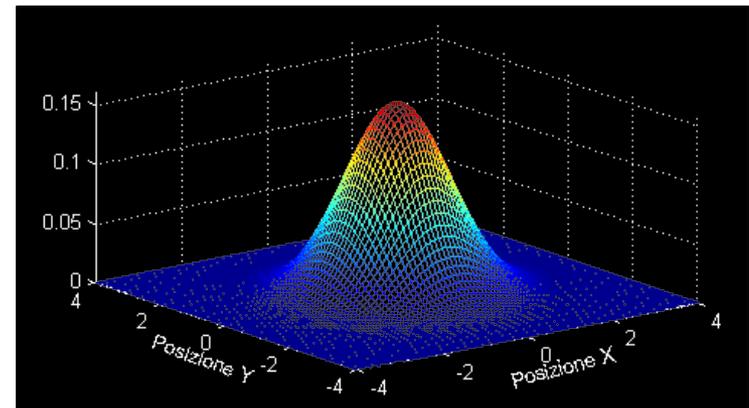


Proton Beam main specs

Energy	70 MeV
Current	750 μA
Power	52.5 kW

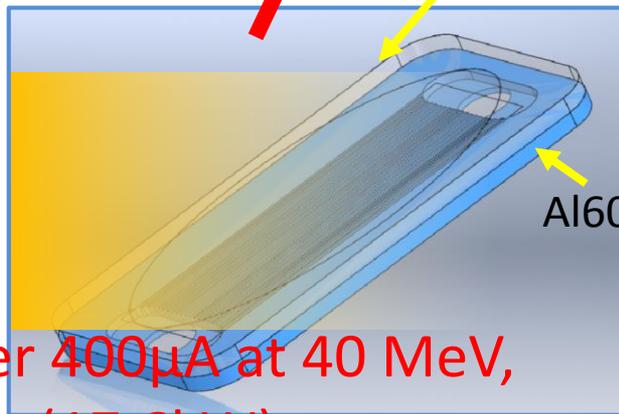
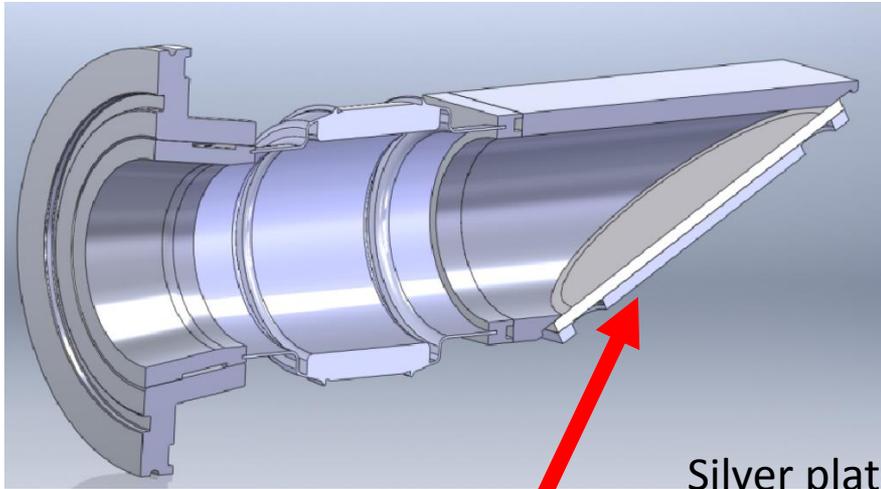
Beam shape main assumption:

Gaussian Profile Distribution



The LPBD system by BEST[®] Theratronics

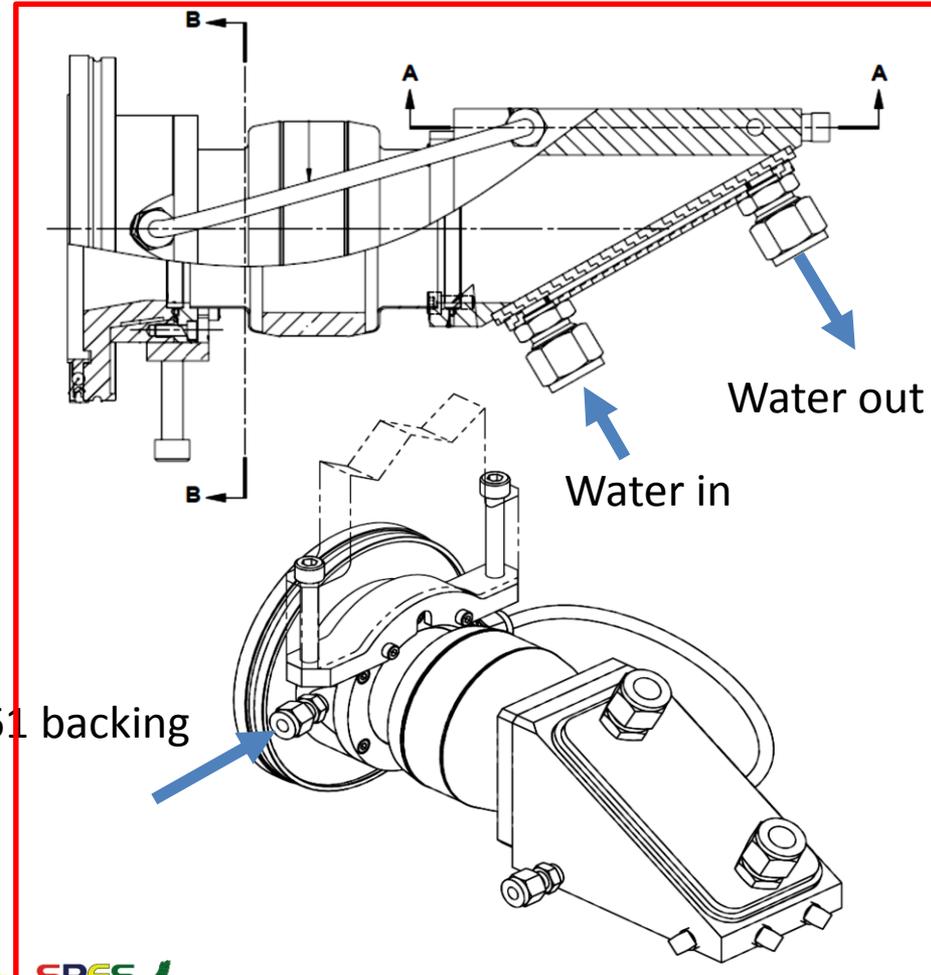
- Tilted configuration
- BD body holder: Al-6061 T6 alloy & ceramic/KOVAR insulator
- BD beam facing/stop wall: silver plate bonded/brazed on Al-6061 T6 Alloy
- No rad. shielding considered !!!! (RP issues or very low power tests in A1 room)



Silver plate

Al6061 backing

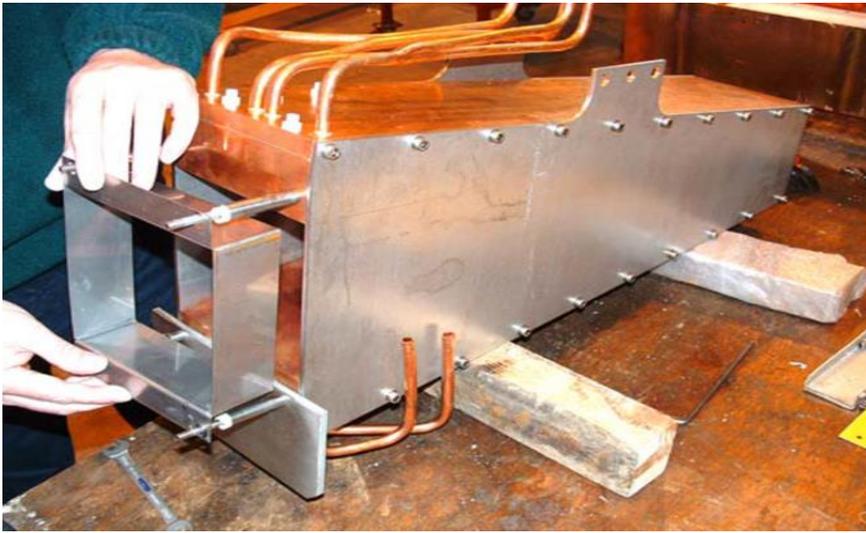
Input power 400 μ A at 40 MeV,
10% margin (17.6kW)



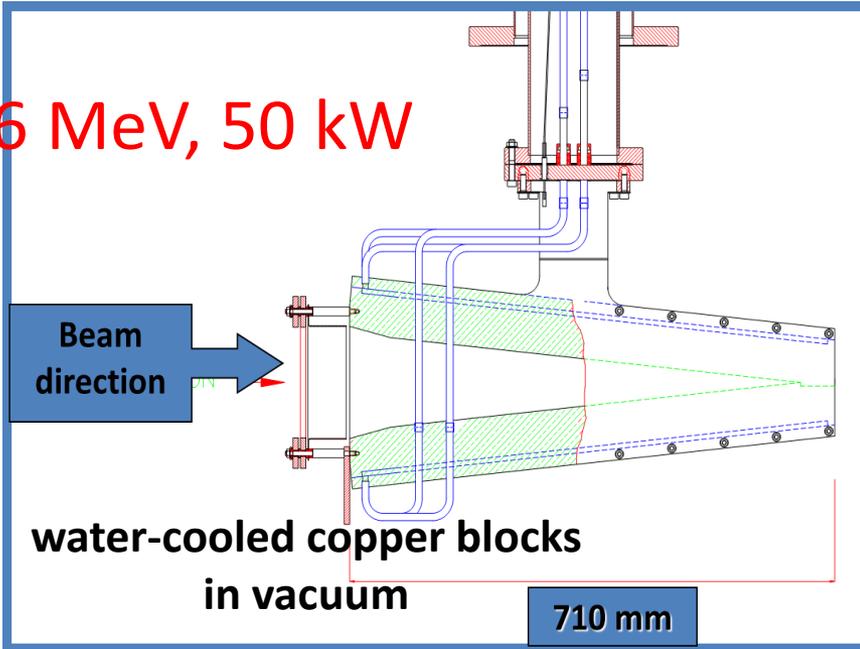
Water out

Water in

The HPBD engineering solutions taken as reference...



66 MeV, 50 kW



- Cu-OFE blocks, V-Shaped-like solution
- (PEFP, Ithemba) has adopted this BD configuration.
- Machining not critical..

Some reference studies on BD best materials....

Main goal: minimize both the prompt radiation and the residual radioactive inventory for BD materials selection

Journal of the Korean Physical Society, Vol. 50, No. 5, May 2007, pp. 1396~1398

Activation Analyses of Beam Dump Materials Irradiated... - Choong-Sup GIL *et al.*

-1397-

Activation Analyses of Beam Dump Materials Irradiated by 100-MeV Protons

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Nuclear Data Evaluation Laboratory, Korea Atomic Energy Research Institute, Daejeon 305-600

(Received 22 November 2006)

Activation of the materials around the beam dump of a proton accelerator and the beam dump itself is one of the most important considerations in the choice of a beam dump material. These activations of the beam dump can have an effect on the operational mode of a proton accelerator. The beam dump should be made of materials that can minimize possible activation. Graphite, aluminum, copper, nickel, iron, and water can be utilized as beam dump materials. In this study, the used materials were irradiated by a 100-MeV proton beam and the radioisotopes produced in the materials were analyzed to choose a beam dump material for low activation.

PACS numbers: 29.27.F, 34.50.B, 14.20.D

Keywords: Beam dump, 100-MeV proton accelerator, Stopping range, Power density, Activation

I. INTRODUCTION

Radiological protection of accelerators is an extremely important aspect of their design. Proton accelerators with a large current under and/or after operation can create a huge amount of radioactive isotopes in the materials around the beam dump. It is desirable to minimize both the prompt radiation production efficiency and the residual activation characteristics [1-4]. The choice of materials is controlled by the power to be dissipated in the beam dump, by shielding considerations, and by a

II. STOPPING RANGE AND POWER DENSITY

To choose the material of a beam dump, MCNPX calculations were carried out [7]. Figure 1 shows the MCNPX calculation model to calculate the residual activities, stopping ranges, and power densities in the materials of the beam dump candidates irradiated by a 100-MeV, 1.6-mA proton beam. The stopping ranges of 100- and 20-MeV protons in the beam dump materials are shown in Table 1. The penetration depths of 100-MeV

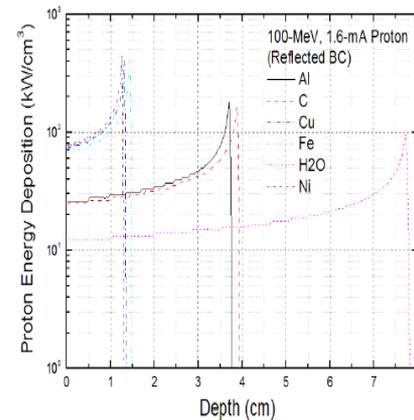


Fig. 2. Power densities for the materials.

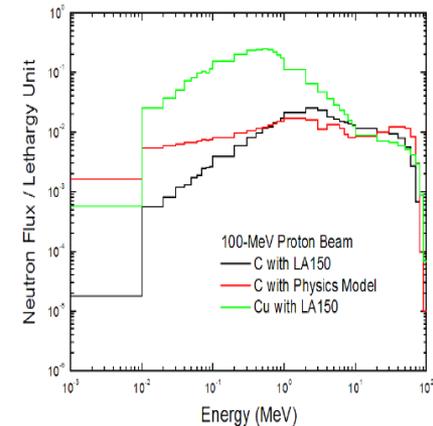


Fig. 4. Neutron spectra for C and Cu.

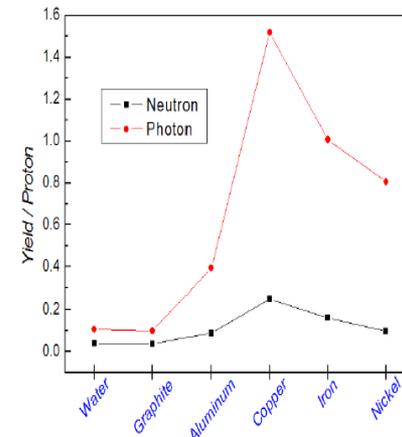


Fig. 3. Comparison of the neutron/photon yields for a 100-MeV proton beam.

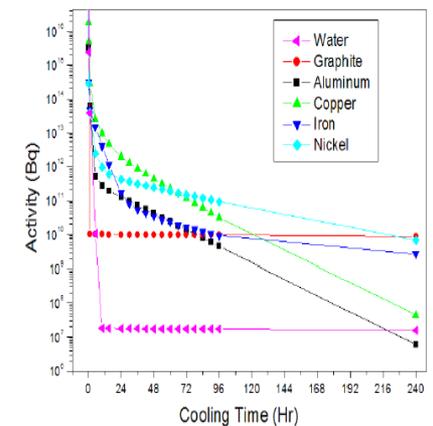


Fig. 5. Residual activities for the materials.

Main BD materials investigation

COPPER

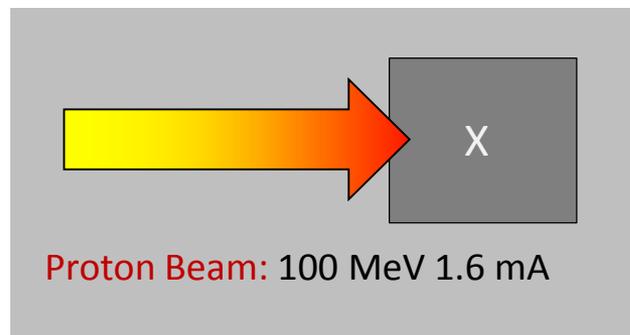
Melting point	1183 °C
Thermal conductivity	390 Wm ⁻¹ K ⁻¹
Density	8930 kg m ⁻³

ALUMINIUM

Melting point	659 °C
Thermal conductivity	290 Wm ⁻¹ K ⁻¹
Density	2750 kg m ⁻³

Stopping depth

Materials	100 MeV
Water	77 mm
Graphite	38.625 mm
Aluminum	36.875 mm
Copper	13.125 mm
Iron	14.325 mm
Nickel	12.525 mm



THEREFORE:

Copper:

- Better Heat dissipation;
- Higher Melting point;
- Reduced Penetration Depth:
S = 8 mm
- Reduced Cooling Time;

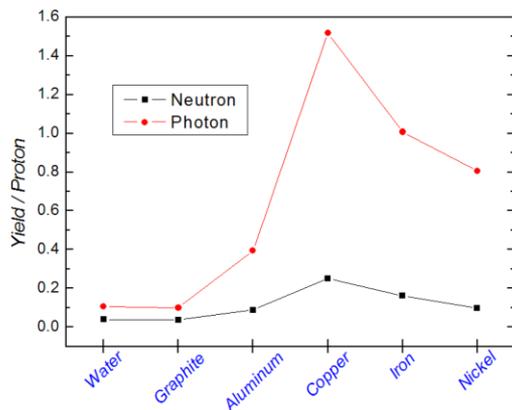
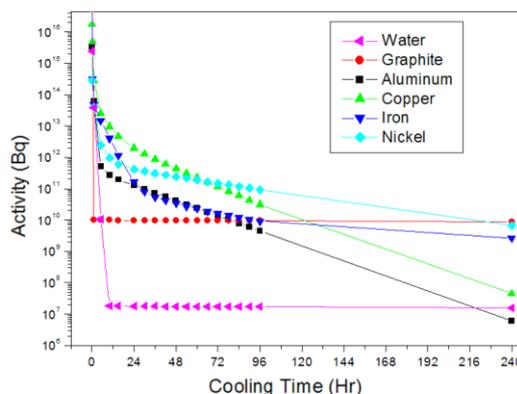
Suitable to the Target!

Aluminium:

- Good Heat dissipation;
- Good Mechanical properties;
- Reduced Cooling Time;

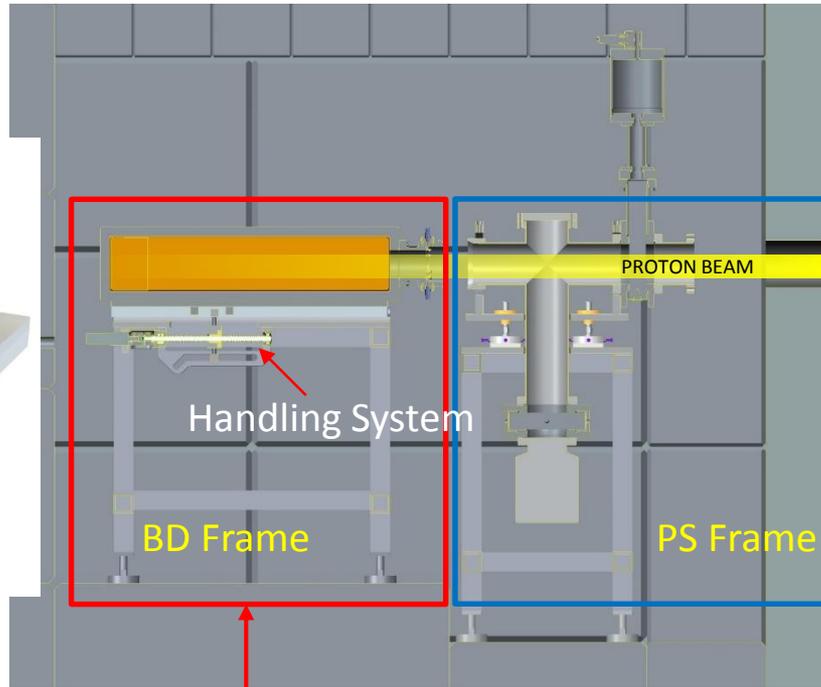
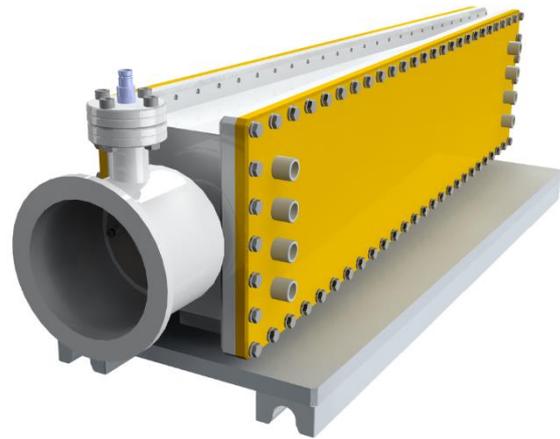
Suitable to the Chamber, support systems...

Residual activities

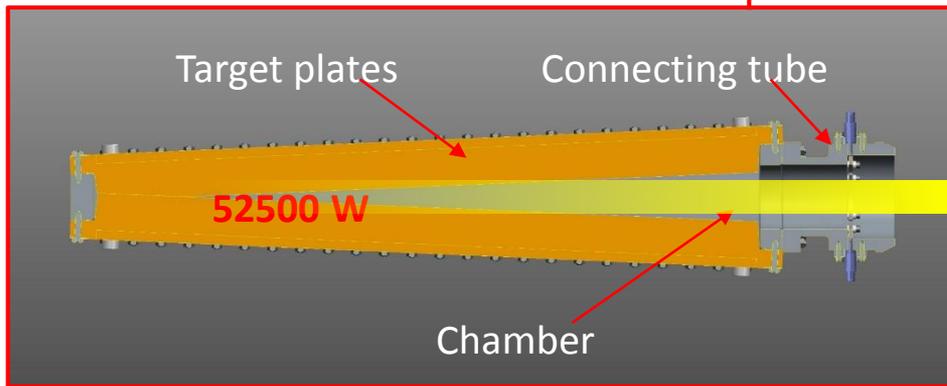
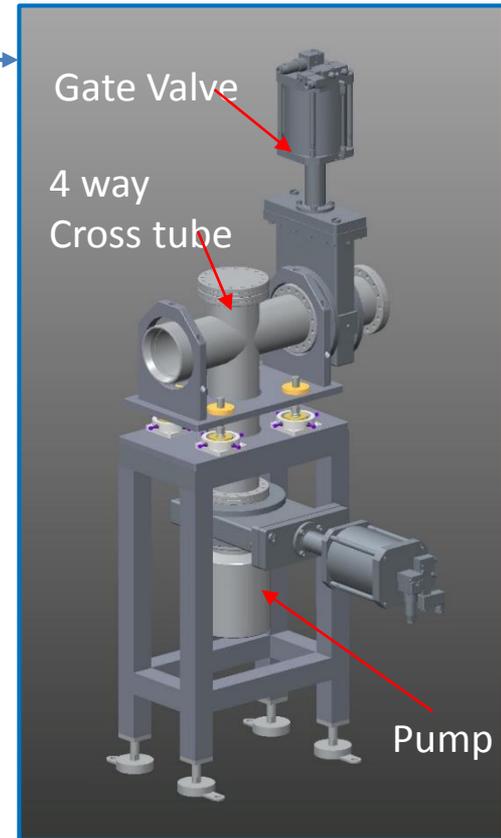


The SPES 50 kW Beam Dump 3D mock-up

BD 3D mock-up



Pump System location under study
NO installation in A6 room but in A1 room



BD Target plates and cooling system parametric studies

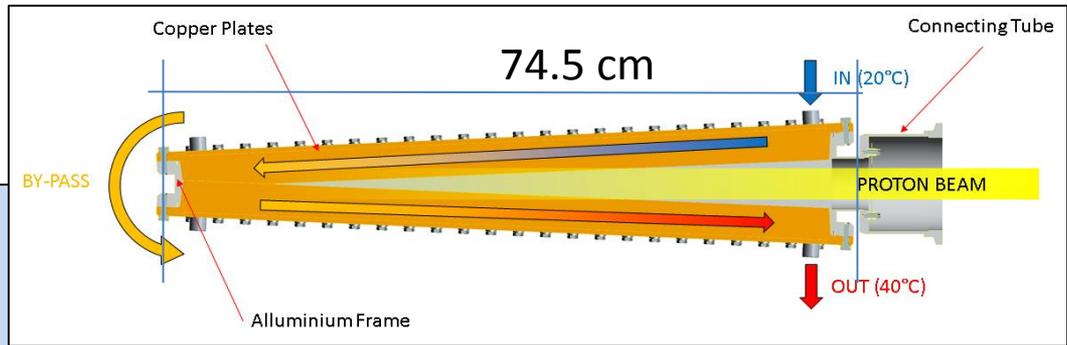


$\alpha <$

Increase the irradiated surface of PB \rightarrow Limits the thermal levels
 Increase depth s
 Increase the total length

$\alpha = 5^\circ$

Heat Dissipation $P = 52,5 \text{ kW}$



INPUT

Water properties at reference T :
 ρ, μ, c_p, λ

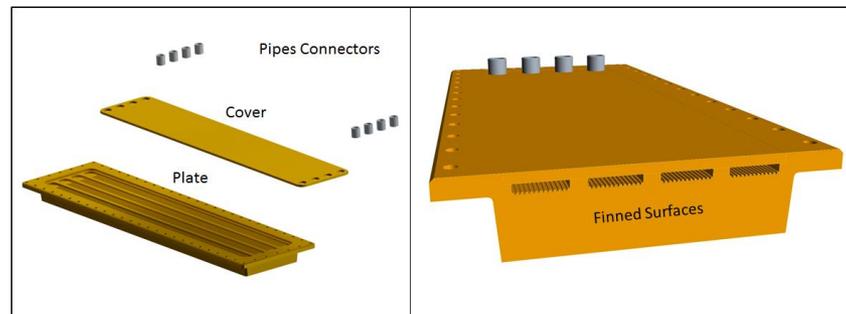
OUTPUT

Fluid dynamic parameters:
 Re, Nu, Pr

Hydraulic properties:

$Q_{tot} = 2400 \text{ l/h}$
 $v = 1,25 \text{ m/s}$

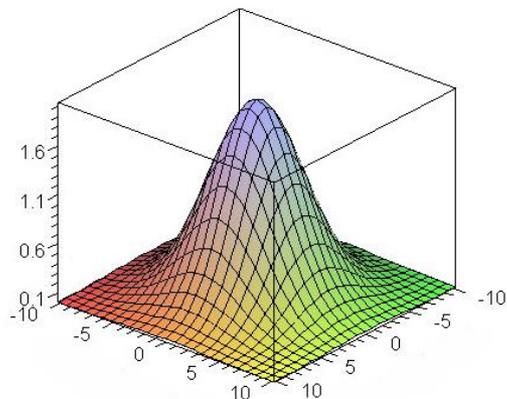
$\Delta t = 20^\circ \text{ C}$
 $\alpha = 7000 \text{ W m}^{-2}\text{K}$



Steady state/transient FEM Analysis (ANSYS)

Thermal-structural analysis were performed to assess the BD thermal distribution inside BD the maximum temperatures during steady state operation as well as critical transients.

Target Plates

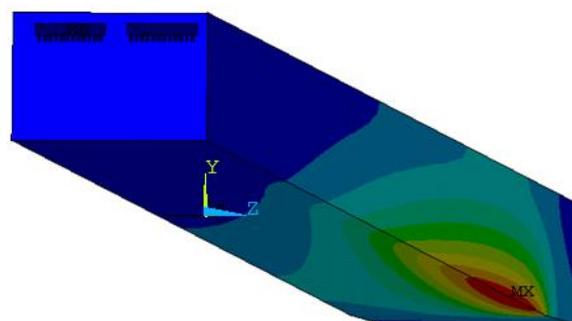
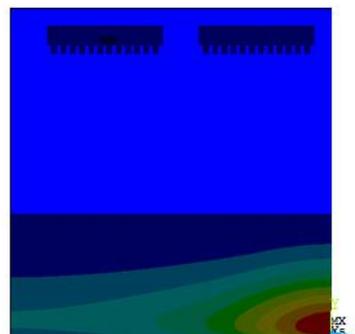
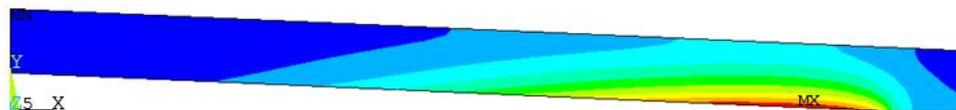
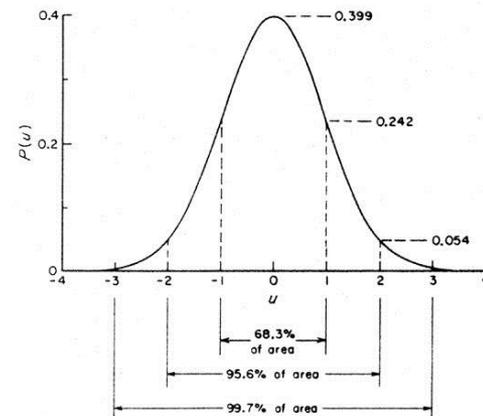


Hp: Gaussian Profile P = 52,5 kW

Degree of Confidence

99,7 % \longleftrightarrow 3σ

	A	B	C	D
σ [mm]	7	8	9	10
D [mm]	42	48	54	60
99,7 %				



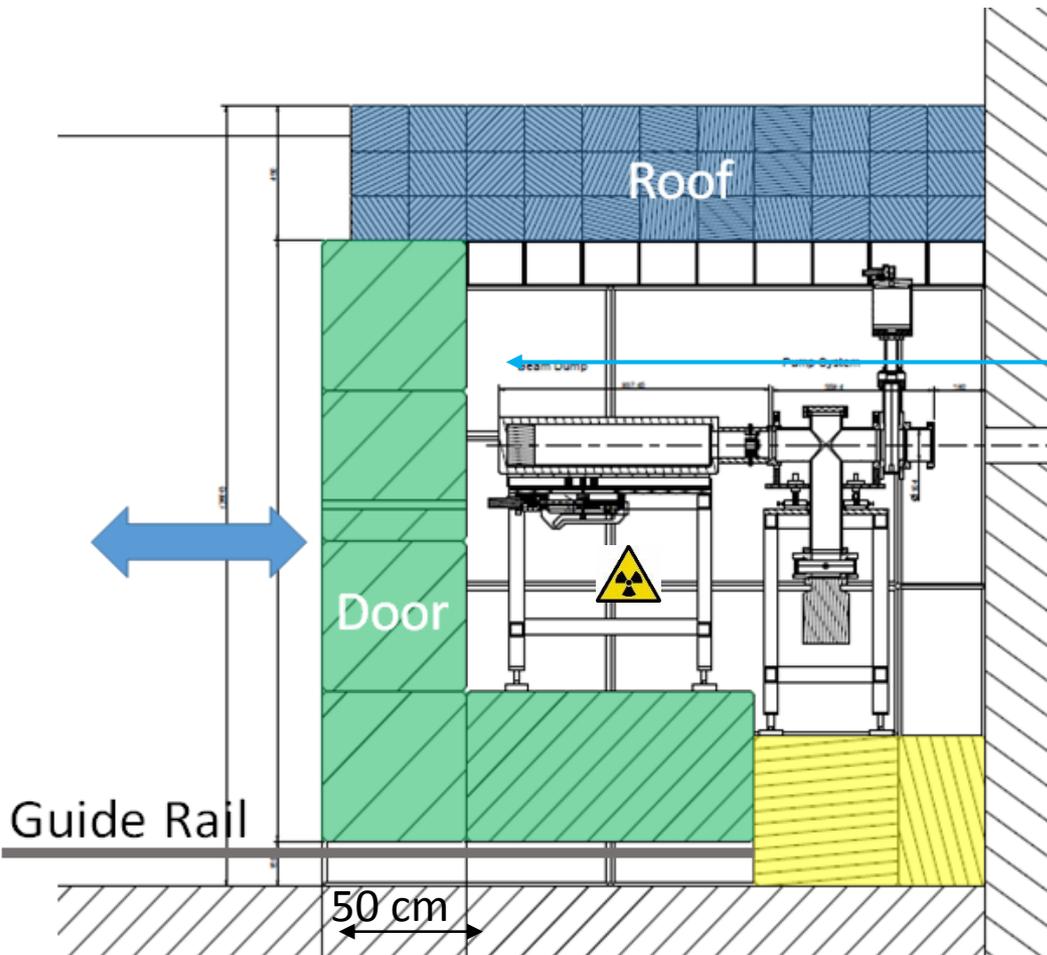
Results

T_s = Max Temperature on system;

T_c = Max Temperature on cooling channels

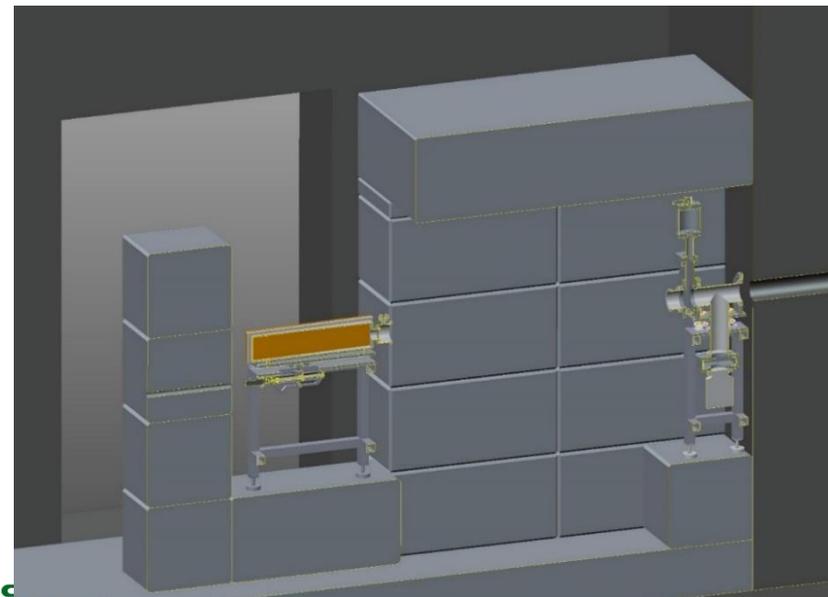
	A	B	C	D
T_s [°C]	328	283	250	223
T_c [°C]	99	93	88	84

BD shielding preliminary modeling (work in progress..)



The BD is located inside a dedicated **Shielding structure**, made of concrete bricks, to prevent excessive air activation load inside A6 room, during commissioning.

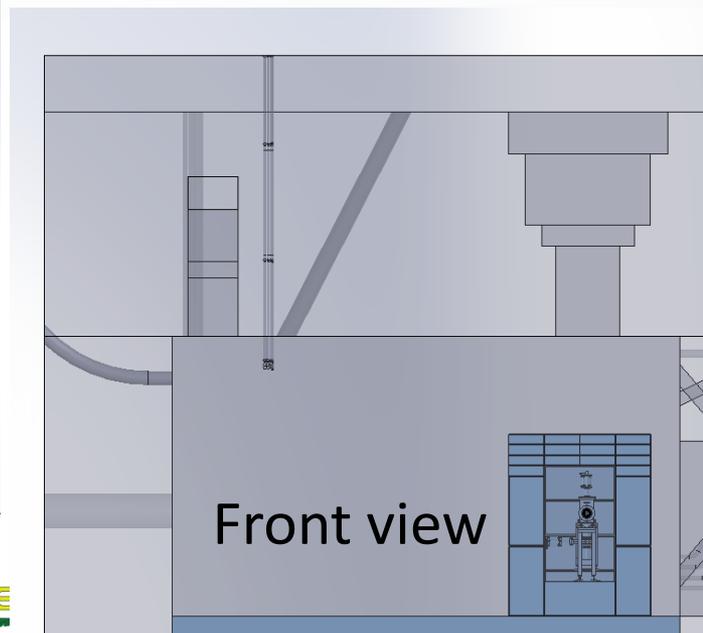
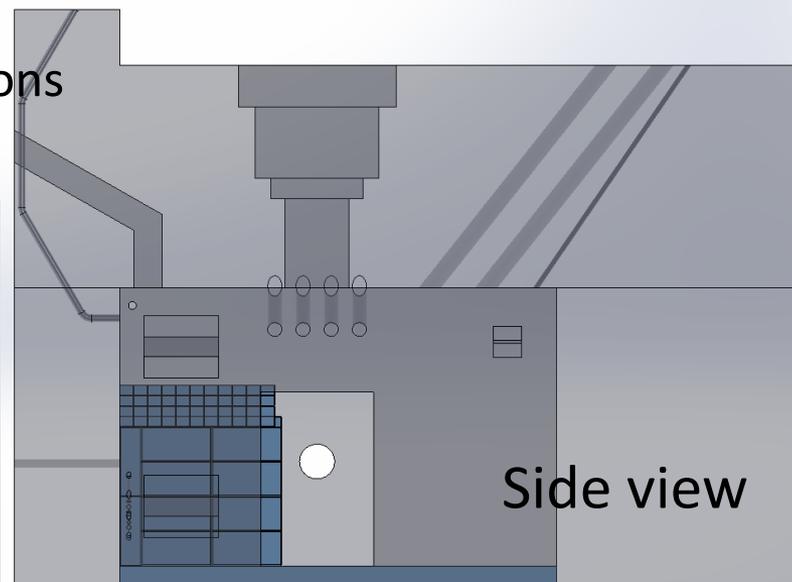
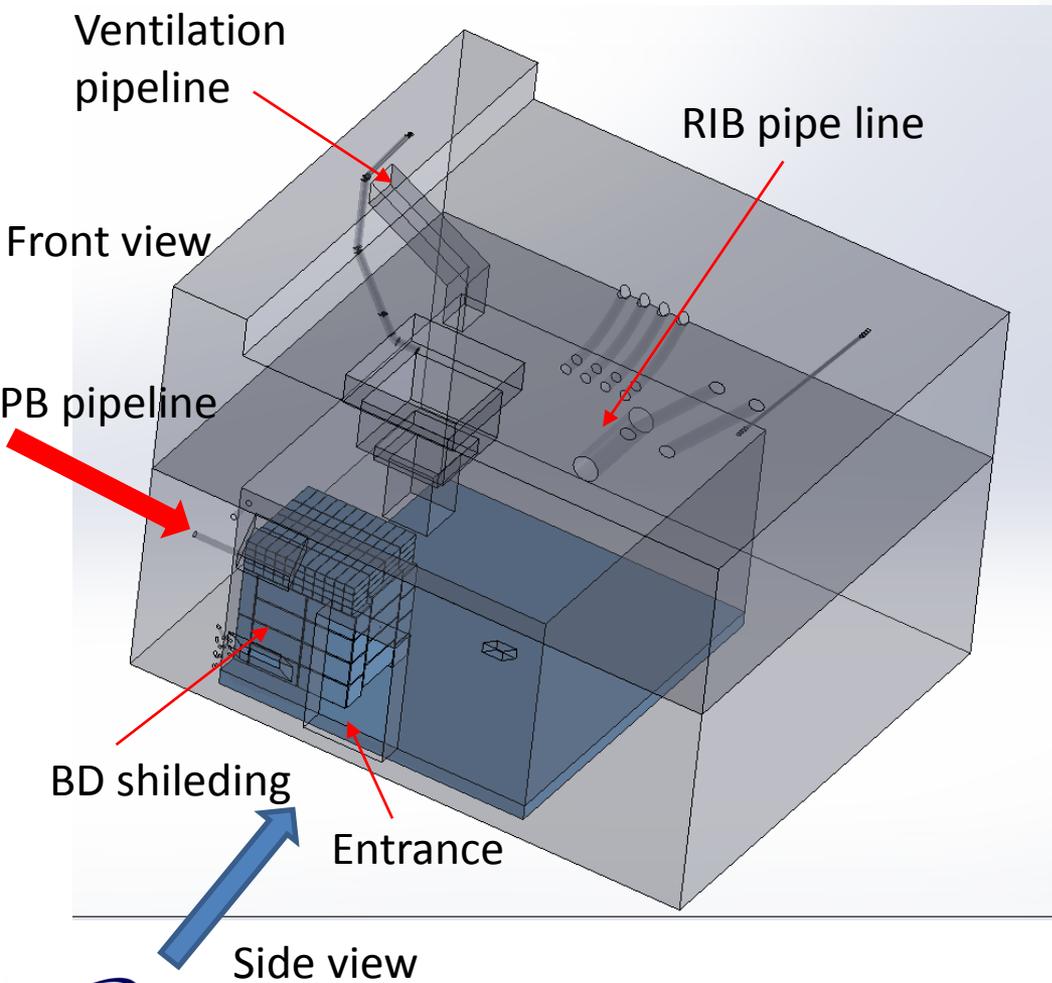
The BD is fixed to a movable (sliding), part of shielding in order to ease the BD removal operations during decommissioning stage



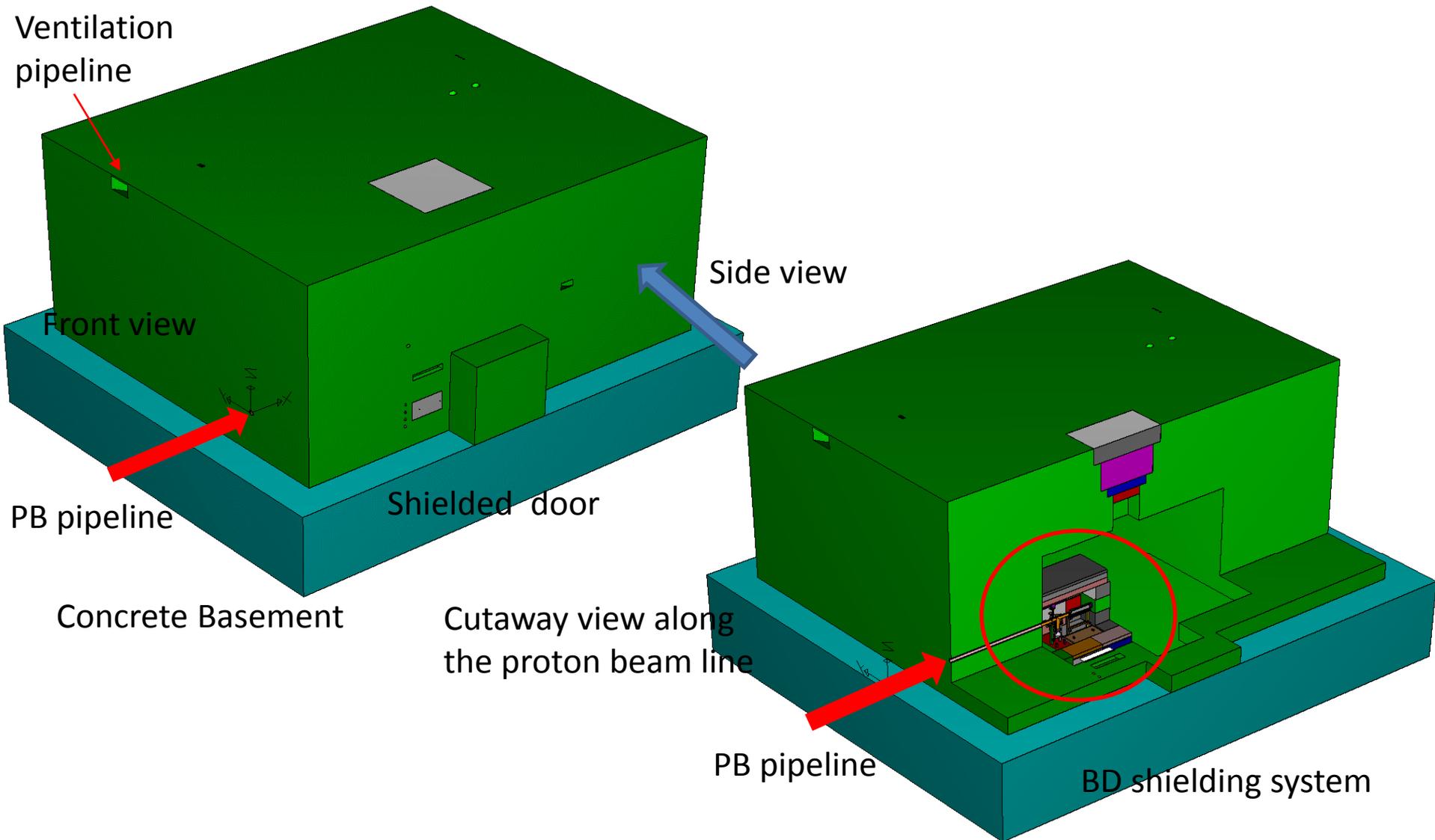
Concrete shielding estimated **TOTAL**
Mass: 5.75 tons

The real 3D geometry for BD system inside the A6 room

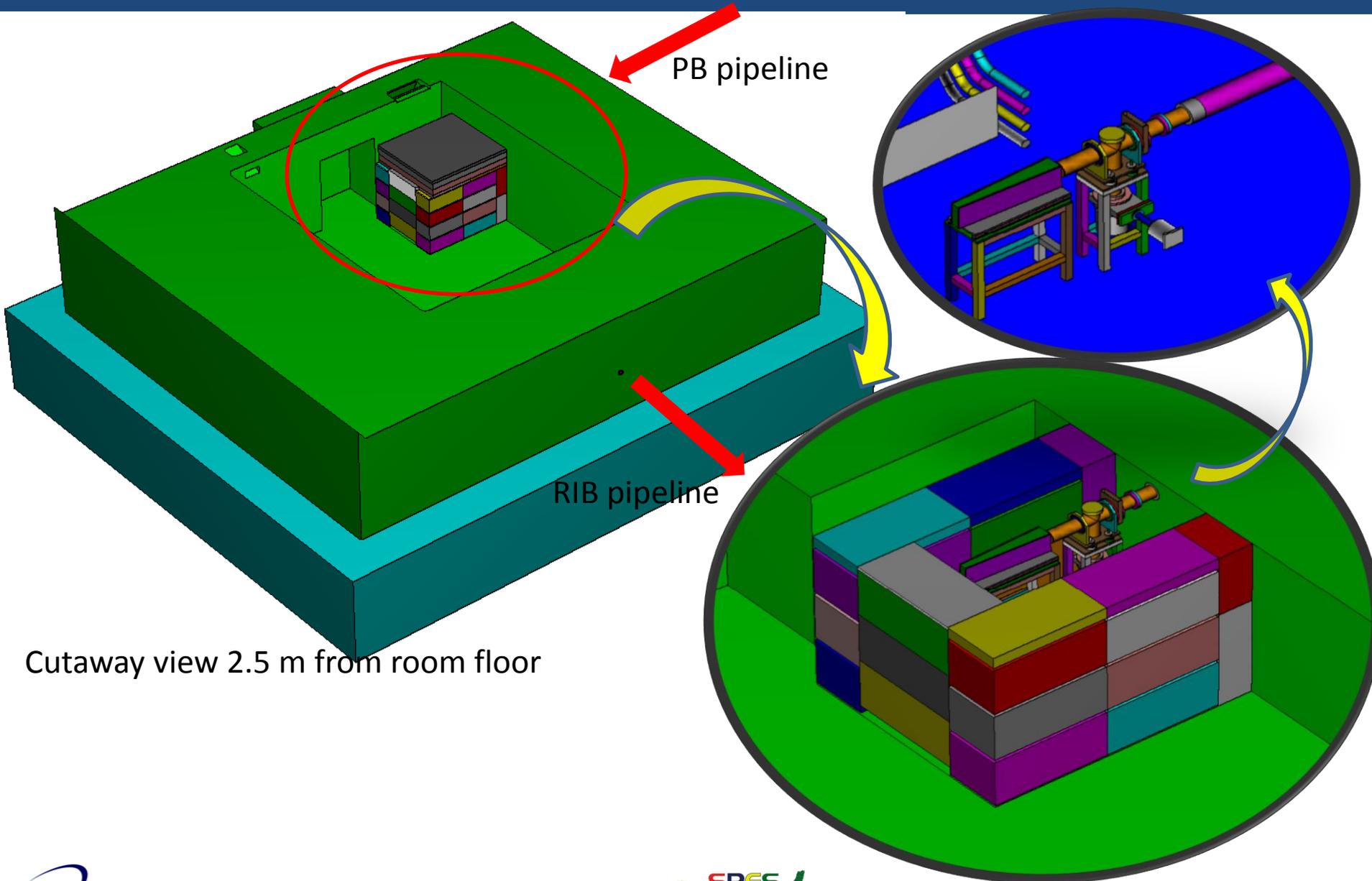
Full 3D view of A6 irr. Room with all penetrations



The MCNPX 3D model of A6 room +BD system

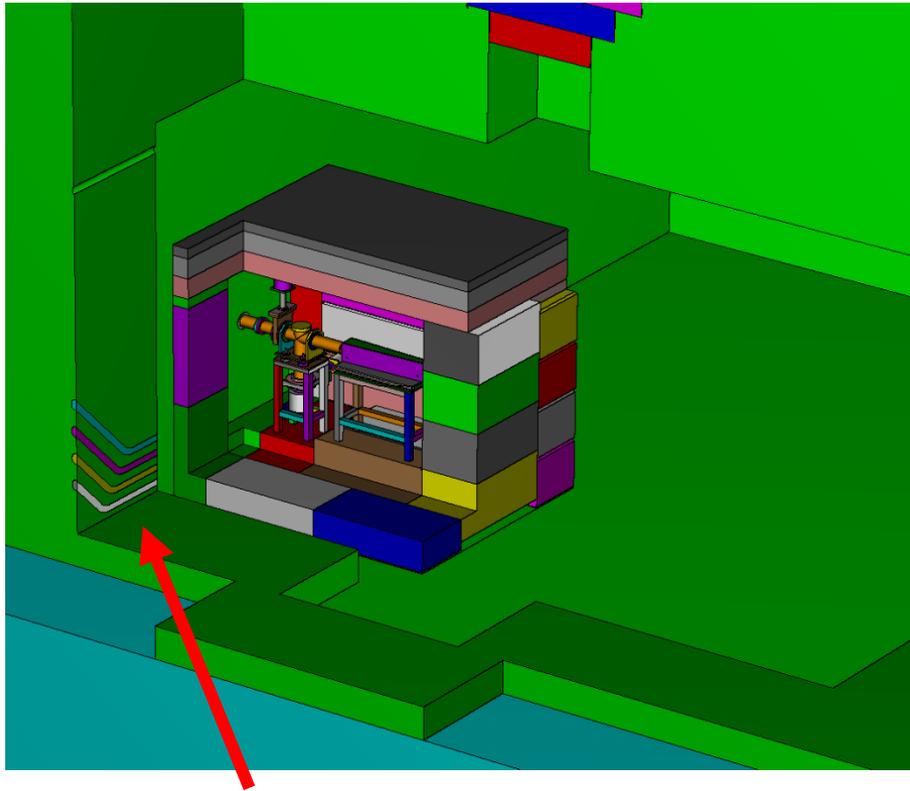


The MCNPX 3D model of A6 room +BD system

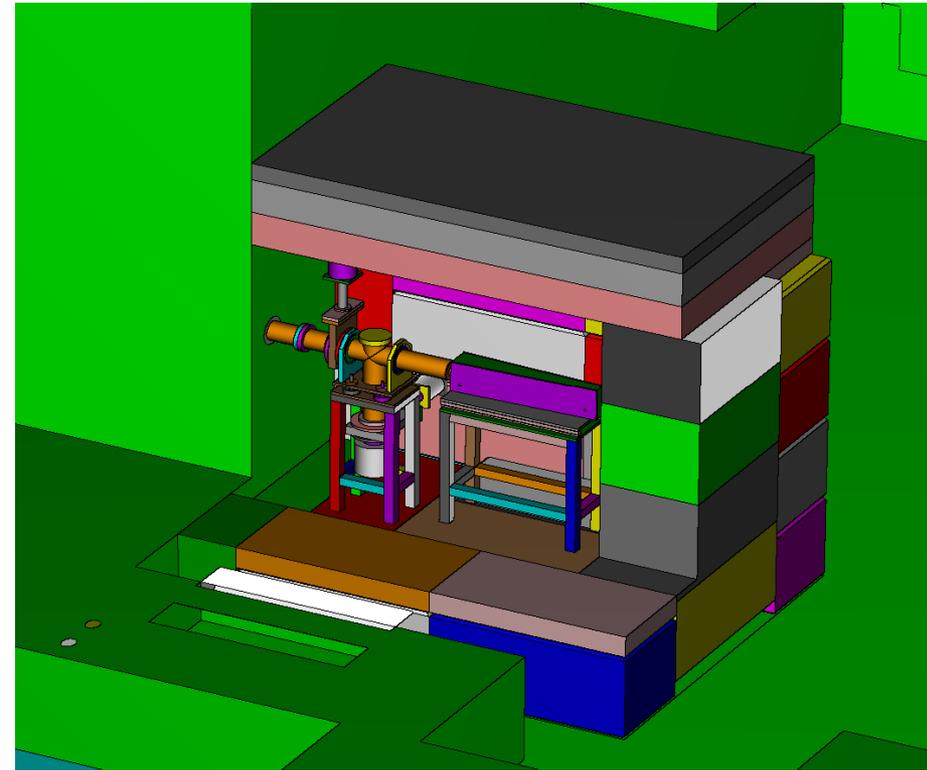


Cutaway view 2.5 m from room floor

The MCNPX 3D model of A6 room +BD system

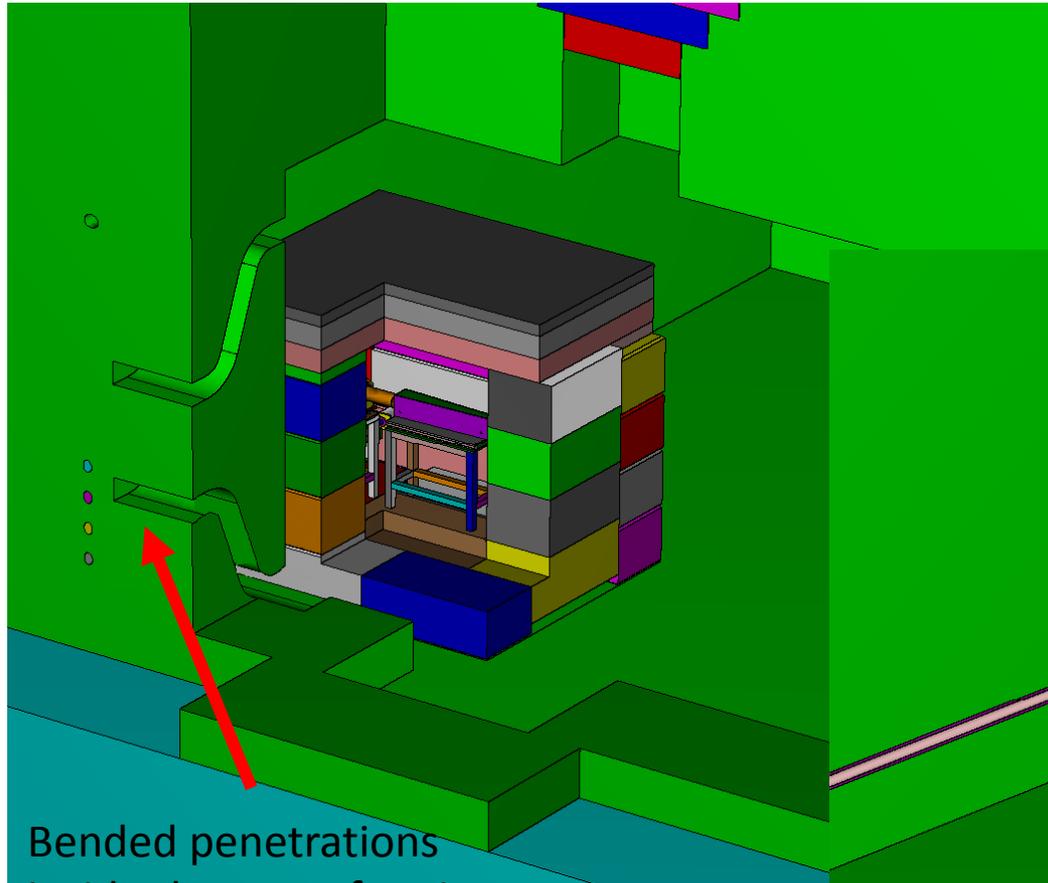


Bended penetrations
inside the room for the
cooling water supply

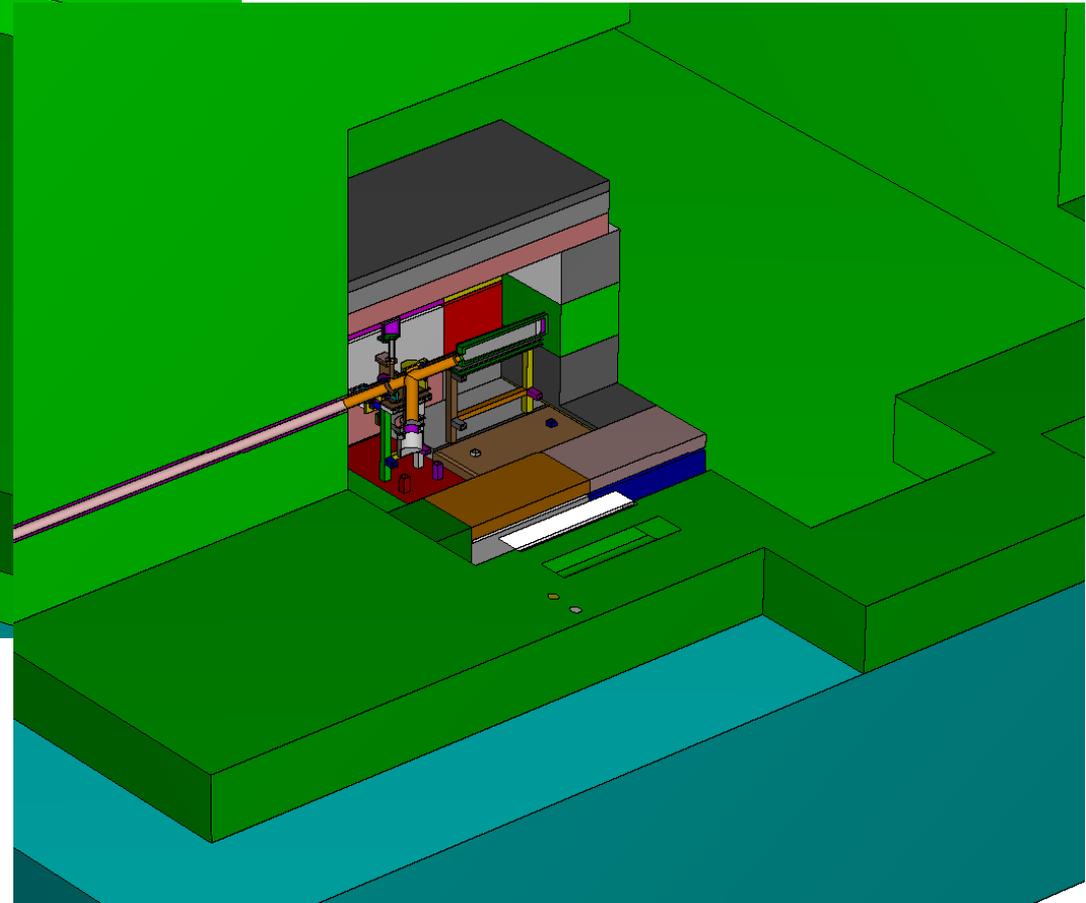


Views of BD system (shielding included) inside the A6 room

The MCNPX 3D model of A6 room +BD system



Cutaway view along beam line
(shielding included) inside the A6 room



Bended penetrations
inside the room for air
venting system

BD structural materials used in MC simulations (FLUKA-MCNPX)

Material n. 1. Cu-OFE: 99.9% purity level

Material n. 2. Al-6082-T6 alloy 99.9% purity level

Alloy components (wt%)

(d=2.736 g/cc)

Al: 97.09

Cu: 0.0540

Fe: 0.2270

Zn: 0.033

Cr: 0.015

Ti: 0.0208

Mn: 0.588

Mg: 0.81

Si: 1.1630

Material n. 3. Standard Portland concrete

Ordinary concrete

(Portland) wt%

(d=2.3 g/cc)

H 1.000 \$ H-nat

C 0.100 \$ C-nat

O 53.00 \$ O-nat

Na 1.600 \$ Na-nat

Mg 0.200 \$ Mg-nat

Al 3.400 \$ Al-nat

Si 33.70 \$ Si-nat

K 1.200 \$ K-nat

Ca 4.400 \$ Ca-nat

Fe 0.078 \$ Fe-54

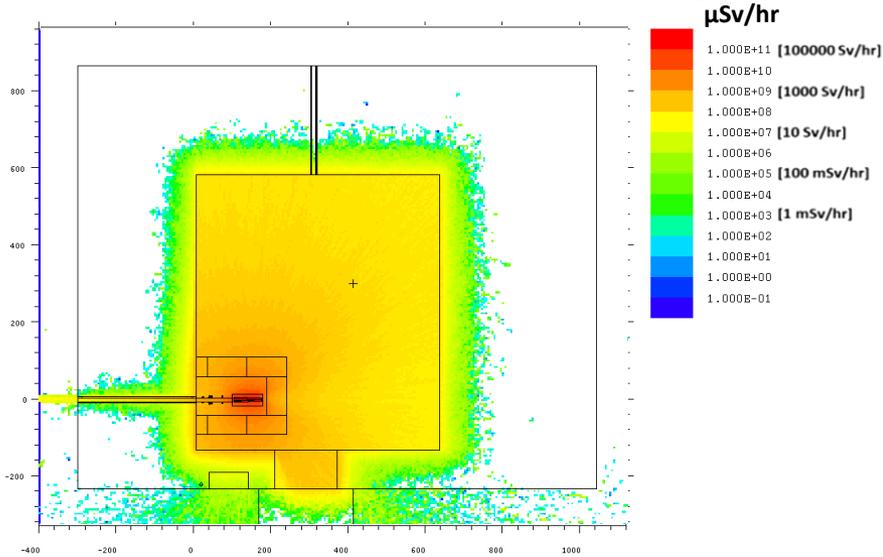
Fe 1.288 \$ Fe-56

Fe 0.030 \$ Fe-57

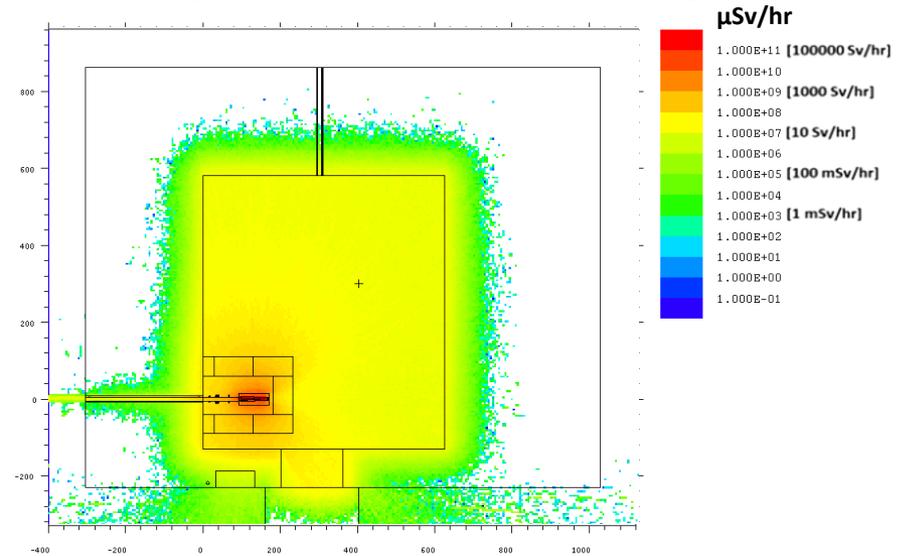
Fe 0.004 \$ Fe-58

Neutron/gamma prompt dose-rate equivalent maps (same color scale) around SPES HPBD (Top view) (MCNPX calcs)

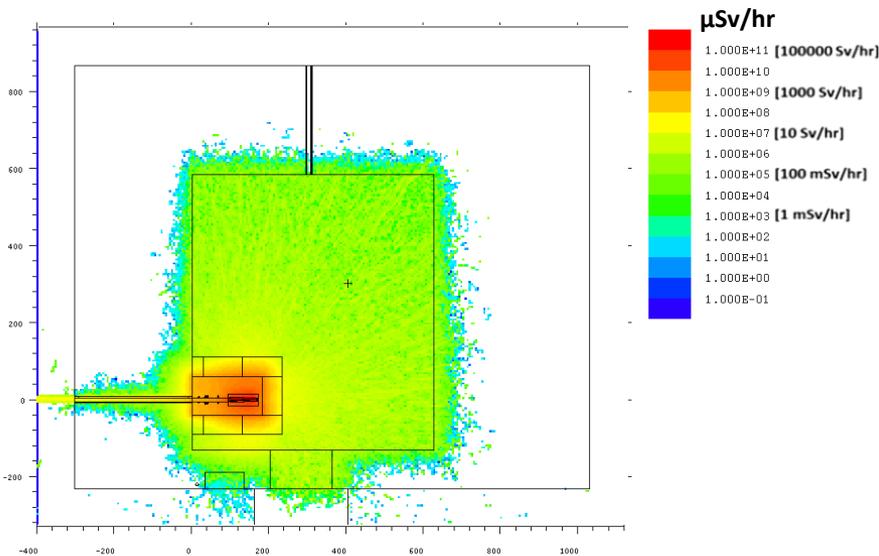
Cu-OFE neutron prompt dose-rate NO Shielding



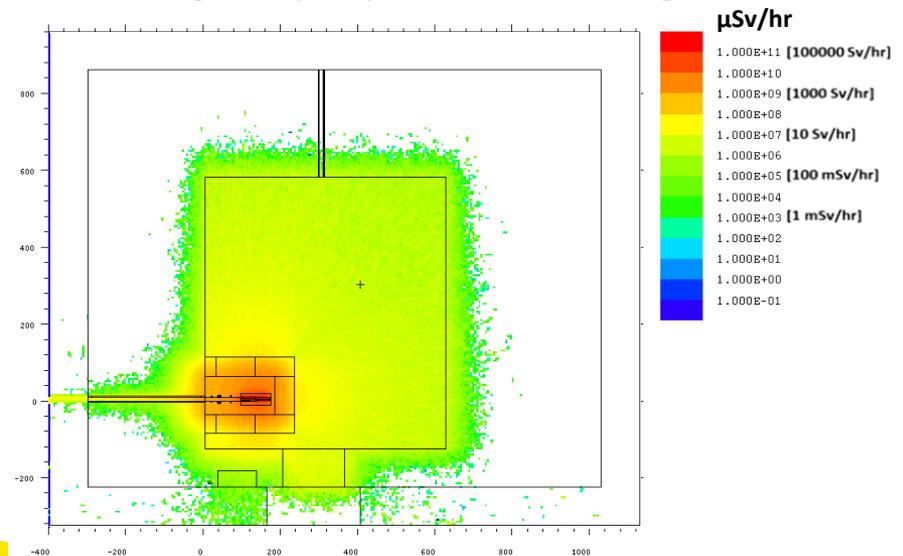
Cu-OFE gamma prompt dose-rate NO Shielding



Cu-OFE neutron prompt dose-rate – Shielding included



Cu-OFE gamma prompt dose-rate – Shielding included



Air activation calcs

reference case: $E_p=70$ MeV, 52.5 kW

5 days beam time

ISOL bunker air volume: 173.57 m^3

$50 \text{ m}^3/\text{h}$ fixed air ventilation renewal rate

(reference ventilation rate so far taken into account (SPES α stage licencing request))

Air activation with BD shielding (MCNPX calcs) 1/2

Volume-weighted (i.e. air inside-outside BD shielding) overall radionuclides inventory expected at reference commissioning scenario : (50 m³/h)

Main design requirement by Italian regulation: $C_A \leq 1$ Bq/g

Isotope	Yield rate [s ⁻¹]	Rel Err. [%]	t _{1/2} (s)	λ (s ⁻¹)	A(t) (Bq)	C _{As} (Bq/g)	C _{Aeq} (Bq/g)	RA (Bq/g)	RA delay (10 min) (Bq/g)
H-3	2.33E+09	2.38	3.89E+08	1.78E-09	1.80E+06	1.21E+04	6.13E+03	2.16E-05	2.16E-05
He-4	1.01E+10	0.90		stable					
Li-6	1.31E+08	9.76		stable					
Li-7	2.64E+08	3.56		stable					
Be-7	9.32E+06	29.75	4.60E+06	1.51E-07	5.87E+05	4.84E+01	2.00E+03	7.28E-06	7.28E-06
Be-9	1.65E+08	9.09		stable					
Be-10	6.55E+07	8.37	4.76E+13	1.46E-14	4.12E-01	3.40E+02	1.41E-03	4.95E-12	4.95E-12
B-10	5.15E+08	5.76		stable					
B-11	7.26E+09	0.25		stable					
B-12	6.64E+04	0.14	2.02E-02	3.43E+01	6.64E+04	3.45E-01	2.27E+02	2.76E-05	0.00E+00
B-13	2.18E+07	93.23	1.73E-02	4.01E+01	2.18E+07	1.13E+02	7.44E+04	9.06E-03	0.00E+00
C-11	6.55E+07	53.83	1.22E+03	5.67E-04	6.55E+07	3.40E+02	2.23E+05	2.38E-02	1.70E-02
C-12	2.33E+09	2.38		stable					
C-13	2.72E+09	1.68		stable					
C-14	6.94E+11	0.06	1.81E+11	3.84E-12	1.15E+06	3.60E+06	3.92E+03	1.38E-05	1.38E-05
N-13	2.89E+08	7.74	5.98E+02	1.16E-03	2.89E+08	1.50E+03	9.84E+05	1.12E-01	5.59E-02
N-14	1.14E+10	1.49		stable					

Main air renewal rates and related concentration activities:

C_{As} = at saturation,

C_{Aeq} = at equilibrium into room

RA= C_A removed by the ventilation system

RA delay = C_A after a given delay time prior to being exhausted

Air activation with BD shielding (MCNPX calcs) 2/2

Volume-weighted (i.e. air inside-outside BD shielding) overall radionuclides inventory expected at reference commissioning scenario : (50 m³/h)

Main design requirement by Italian regulation: $C_A \leq 1$ Bq/g

Isotope	Yield rate [s ⁻¹]	Rel Err. [%]	t _{1/2} (s)	λ (s ⁻¹)	A(t) (Bq)	C _{As} (Bq/g)	C _{Aeq} (Bq/g)	RA (Bq/g)	RA delay (10 min) (Bq/g)
N-15	2.88E+10	0.20		stable					
N-16	4.76E+07	4.45	7.13E+00	9.722E-02	4.76E+07	2.47E+02	2.34E+02	1.98E-02	9.20E-28
O-15	5.30E+07	15.51	1.22E+02	5.670E-03	5.30E+07	2.75E+02	2.61E+02	2.17E-02	7.23E-04
O-16	3.56E+09	2.61		stable					
O-17	1.93E+07	0.14		stable					
S-35	3.10E+06	6.63	7.55E+06	9.185E-08	1.21E+05	1.61E+01	5.95E-01	1.48E-06	1.48E-06
S-36	4.53E+05	15.79		stable					
S-37	2.17E+05	12.82	3.03E+02	2.288E-03	2.17E+05	1.13E+00	1.07E+00	8.70E-05	2.21E-05
Cl-38	1.06E+05	19.02	2.23E+03	3.102E-04	1.06E+05	5.50E-01	5.22E-01	3.50E-05	2.90E-05
Cl-39	4.14E+05	23.15	3.37E+03	2.056E-04	4.14E+05	2.15E+00	2.04E+00	1.24E-04	1.09E-04
Cl-40	4.84E+05	11.40	8.10E+01	8.557E-03	4.84E+05	2.51E+00	2.38E+00	1.99E-04	1.17E-06
Ar-37	1.52E+06	6.03	3.03E+06	2.290E-07	1.43E+05	7.88E+00	7.04E-01	1.80E-06	1.80E-06
Ar-38	4.99E+07	24.41	2.23E+03	3.102E-04	4.99E+07	2.59E+02	2.46E+02	1.65E-02	1.37E-02
Ar-39	3.12E+07	12.94	8.48E+09	8.171E-11	1.10E+03	1.62E+02	5.42E-03	1.32E-08	1.32E-08
Ar-40	2.31E+08	16.08		stable					
Ar-41	1.56E+09	1.41	6.56E+03	1.057E-04	1.56E+09	8.12E+03	7.71E+03	3.70E-01	3.47E-01
TOTAL					2.10E+09	3.625E+06	1.30E+06	5.73E-01	4.35E-01

Main air renewal rates and related concentration activities:
 C_{As} = at saturation,
 C_{Aeq} = at equilibrium into room
RA = C_A removed by the ventilation system
RA delay = C_A after a given delay time prior to being exhausted

MAIN RESULT: BASICALLY NO air delay line needed to get $RA \leq 1$ Bq/g

BD H₂O cooling activation calcs

reference case: $E_p=70$ MeV, 52.5 kW

5 days beam time

1 week cooling....

time short enough for possible personnel intervention in A17 room (technical plant, first floor) around the cooling system

MCNPX calcs

The cooling system plant in ISOL 1 bunker

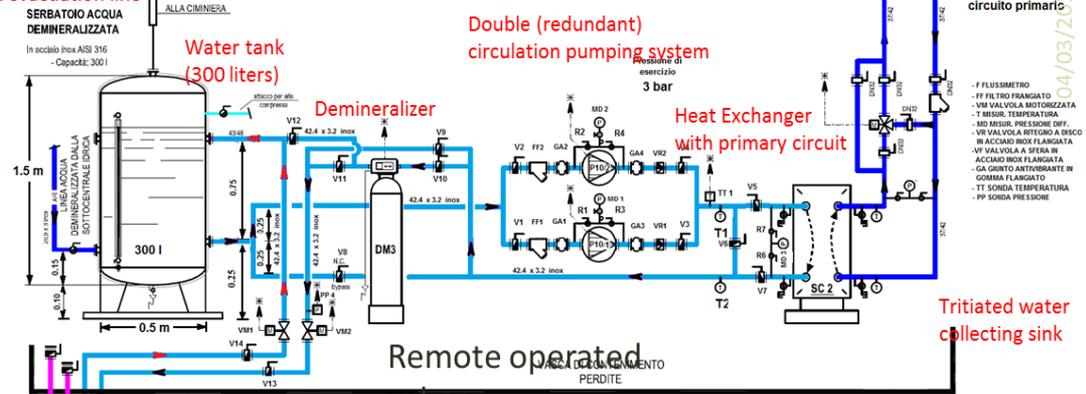
Total water volume in the whole cooling loop

H₂O volume inside the water tank ~250 liter
 water volume inside BD ~0.84 liter
 Connecting pipes total vol. ~50 liter
TOTAL ~301 liter

FAS:
 Ramp Up
 avvio pompe (event. calibrazione)
 avvio riscaldatore
 breve scopp. risc.
 avvio fascio (start fascio 1500/1700 °C)
 Ramp Down

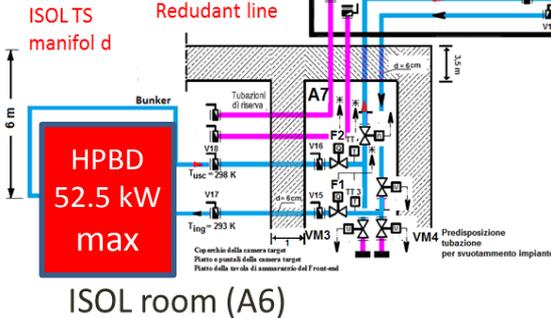
Water radiolyses H₂, O₂ gas recovery & evacuation line

room A17 (upstairs)



Starting BD cooling data

Beam power	52.5	kW
Water temp. drop (tentative)	20	K
cp H ₂ O	4.186	KJ/Kg·K
Mass flow rate needed	37.63	Kg/min



Remote operated valves

RAFFREDDAMENTO TARGET

BD mass flow rate required	~37.6 Liters/min
Elapsed time for the entire cooling water volume to flow through the BD	8.0 min
N. of water turns per hour inside BD	7.504
Estimated stay time per each water volume inside BD	0.0223 min
effective irradiation time expected per each BD water volume after 1 hr beam	0.1675 min

BD cooling H₂O activation level expected (5 days beam on) (MCNPX calcs)

Isotope	Yield rate [s ⁻¹]	Rel Err. [%]	t _{1/2} (s)	λ (s ⁻¹)	A(EOB) (Bq)	C _{As} (Bq/g)	C _A (EOB) (Bq/g)	C _A (EOB+Δt) (168 hrs) (Bq/g)
H-1	2.34E+07	100.00		stable				
H-2	4.90E+10	0.47		stable				
H-3	5.55E+08	25.02	3.89E+08	1.784E-09	4.274E+05	5.945E+08	1.421E+00	1.419E+00
Li-6	7.02E+07	80.47		stable				
Li-7	4.92E+08	30.78		stable				
Be-7	1.17E+08	62.93	4.60E+06	1.505E-07	7.365E+06	1.214E+08	2.448E+01	2.235E+01
Be-9	1.40E+08	56.90		stable				
Be-10	2.11E+08	42.54	4.76E+13	1.456E-14	1.327E+00	2.257E+08	4.411E-06	4.411E-06
B-10	2.20E+09	12.74		stable				
B-11	2.43E+09	12.72		stable				
B-12	6.09E+08	27.72	2.02E-02	3.431E+01	0.000E+00	0.000E+00	0.000E+00	0.000E+00
C-11	2.47E+10	3.45	1.22E+03	5.666E-04	2.148E+10	9.413E+07	7.141E+04	1.088E-144
C-12	6.08E+10	1.86		stable				
C-13	3.84E+10	1.43		stable				
C-14	1.68E+09	13.35	1.81E+11	3.836E-12	2.777E+03	1.796E+09	9.230E-03	9.230E-03
C-15	7.02E+07	80.47	2.45E+00	2.830E-01	8.516E-50	8.971E-55	2.831E-55	0.000E+00
N-13	2.27E+09	12.00	5.98E+02	1.159E-03	1.696E+09	3.633E+06	5.638E+03	1.767E-301
N-14	1.34E+10	5.55		stable				
N-15	1.30E+10	4.36		stable				
N-16	2.84E+09	3.99	7.13E+00	9.722E-02	6.919E-10	1.884E-14	2.300E-15	0.000E+00
O-15	4.03E+09	10.78	1.22E+02	5.670E-03	7.692E+08	3.379E+05	2.557E+03	0.000E+00
O-16	2.33E+11	1.47		stable				
O-17	1.31E+08	53.58		stable				
O-18	1.73E+05	100.00		stable				

ISOLDE cooling water
activation @1 week beam off
(J. Voltaire private communication)

H-3 40 Bq/g (many runs result)
Be-7 30 Bq/g

Basically the water activation level is similar to what measured at ISOLDE after 1 week cooling

TOTAL

2.40E+10 2.84E+09 7.96E+04 2.38E+01

exotic beams for science

J. Esposito, July 23, 2015

BD concrete shielding activation

reference case: $E_p=70$ MeV, 52.5 kW

5 days beam time

2 weeks cooling

(time slot taken as reference for SPES target removal with remote controlled system). Possible intervention inside the the A6 room

Portland standard (2.3 g/cc)

BD shielding total volume: ~ 2.5 m³

concrete mass: 5.75 ton

MCNPX calcs

Radioactive Inventory inside concrete (1/5)

Isotope	Yield rate [s ⁻¹]	Rel Err. [%]	t _{1/2} (s)	λ (s ⁻¹)	A(EOB) (Bq)	C _A (EOB) (Bq/g)	A(EOB+Δt) (336 hrs) (Bq)	C _A (EOB+Δt) (336 hrs) (Bq/g)
H-2	1.403E+14	0.06		stable			0.00E+00	0.00E+00
He6	7.022E+07	57.74	8.06E-01	8.60E-01	7.02E+07	1.22E+01	0.00E+00	0.00E+00
Li-6	3.886E+09	7.76		stable				
Li-7	2.725E+10	2.94		stable				
Li-8	4.213E+08	23.57	8.38E-01	8.27E-01	4.21E+08	7.33E+01	0.00E+00	0.00E+00
Li-9	2.341E+07	100.00	1.78E-01	3.89E+00	2.34E+07	4.07E+00	0.00E+00	0.00E+00
Be-7	6.250E+09	6.19	4.60E+06	1.505E-07	3.94E+08	6.84E+01	3.28E+08	5.70E+01
Be-8	3.277E+08	26.73	1.00E-04	6.931E+03	3.28E+08	5.70E+01	0.00E+00	0.00E+00
Be-9	1.542E+10	3.31		stable				
Be-10	4.677E+09	7.05	4.76E+13	1.456E-14	2.94E+01	5.11E-06	2.94E+01	5.11E-06
Be-11	3.979E+08	24.25	1.38E+01	5.019E-02	3.98E+08	6.92E+01	0.00E+00	0.00E+00
B-10	1.662E+10	3.78		stable				
B-11	3.113E+11	0.88		stable				
B-12	4.460E+10	2.29	2.02E-02	3.431E+01	4.46E+10	7.76E+03	0.00E+00	0.00E+00
B-13	1.404E+08	40.82	1.73E-02	4.007E+01	1.40E+08	2.44E+01	0.00E+00	0.00E+00
C-10	7.022E+07	57.74	1.92E+01	3.605E-02	7.02E+07	1.22E+01	0.00E+00	0.00E+00
C-11	4.853E+10	2.21	1.22E+03	5.666E-04	4.85E+10	8.44E+03	1.13E-287	1.96E-294
C-12	3.678E+12	0.29	1.00E-04	stable				
C-13	6.274E+12	0.13	1.00E-04	stable				
C-14	1.837E+11	1.14	1.81E+11	3.84E-12	3.04E+05	5.29E-02	3.04E+05	5.29E-02
C-15	5.969E+09	6.26	2.45E+00	2.83E-01	5.97E+09	1.04E+03	0.00E+00	0.00E+00
N-13	9.714E+09	4.91	5.98E+02	1.16E-03	9.71E+09	1.69E+03	0.00E+00	0.00E+00
N-14	3.732E+11	0.81		stable				
N-15	1.427E+12	0.41		stable				
N-16	3.923E+11	0.31	7.13E+00	9.722E-02	3.92E+11	6.82E+04	0.00E+00	0.00E+00
O-14	8.427E+08	16.67	7.06E+01	9.817E-03	8.43E+08	1.47E+02	0.00E+00	0.00E+00
O-15	3.069E+11	0.88	1.22E+02	5.67E-03	3.07E+11	5.34E+04	0.00E+00	0.00E+00
O-16	1.667E+13	0.24		stable				
O-17	2.686E+11	0.06		stable				
O-18	2.341E+07	100.00		stable				

Radioactive Inventory inside concrete (2/5)

Isotope	Yield rate [s ⁻¹]	Rel Err. [%]	t _{1/2} (s)	λ (s ⁻¹)	A(EOB) (Bq)	C _A (EOB) (Bq/g)	A(EOB+Δt) (336 hrs) (Bq)	C _A (EOB+Δt) (336 hrs) (Bq/g)
O-20	4.68E+07	70.71	1.35E+01	5.131E-02	4.68E+07	8.14E+00	0.00E+00	0.00E+00
F-18	1.94E+09	10.98	6.59E+03	1.05E-04	1.94E+09	3.38E+02	1.01E-46	1.75E-53
F-19	4.03E+09	7.67		stable				
F-20	6.61E+08	18.76	1.12E+01	6.21E-02	6.61E+08	1.15E+02	0.00E+00	0.00E+00
F-21	9.13E+08	16.01	4.16E+00	1.67E-01	9.13E+08	1.59E+02	0.00E+00	0.00E+00
F-22	4.68E+07	70.71	4.23E+00	1.64E-01	4.68E+07	8.14E+00	0.00E+00	0.00E+00
Ne-19	2.34E+07	100.00	1.72E+01	4.03E-02	2.34E+07	4.07E+00	0.00E+00	0.00E+00
Ne-20	2.28E+10	3.21		stable				
Ne-21	4.81E+10	2.21		stable				
Ne-22	7.64E+10	1.76		stable				
Ne-23	8.19E+08	16.90	3.72E+01	1.86E-02	8.19E+08	1.42E+02	0.00E+00	0.00E+00
Na-21	4.68E+07	70.71	2.25E+01	3.08E-02	4.68E+07	8.14E+00	0.00E+00	0.00E+00
Na-22	8.45E+10	1.66	8.21E+07	8.45E-09	3.08E+08	5.35E+01	3.05E+08	5.30E+01
Na-23	5.01E+11	0.71		stable				
Na-24	1.61E+13	0.07	5.39E+04	1.29E-05	1.61E+13	2.80E+06	2.78E+06	4.84E-01
Na-25	2.65E+09	9.41	5.91E+01	1.17E-02	2.65E+09	4.60E+02	0.00E+00	0.00E+00
Na-26	3.75E+08	25.00	1.07E+00	6.47E-01	3.75E+08	6.51E+01	0.00E+00	0.00E+00
Mg-23	6.79E+08	18.57	1.13E+01	6.12E-02	6.79E+08	1.18E+02	0.00E+00	0.00E+00
Mg-24	2.59E+11	0.96		stable				
Mg-25	3.56E+11	0.59		stable				
Mg-26	6.62E+11	0.60		stable				
Mg-27	1.40E+11	0.62	5.67E+02	1.22E-03	1.40E+11	2.43E+04	0.00E+00	0.00E+00
Mg-28	5.85E+08	20.00	7.53E+04	9.21E-06	5.74E+08	9.99E+01	8.35E+03	1.45E-03
Mg-29	2.34E+07	100.00	1.30E+00	5.33E-01	2.34E+07	4.07E+00	0.00E+00	0.00E+00
Al-25	3.51E+08	25.82	7.18E+00	9.65E-02	3.51E+08	6.11E+01	0.00E+00	0.00E+00
Al-26	4.46E+11	0.74	2.26E+13	3.07E-14	5.90E+03	1.03E-03	5.90E+03	1.03E-03
Al-27	2.92E+12	0.32		stable				
Al-28	1.27E+13	0.07	1.34E+02	5.15E-03	1.27E+13	2.20E+06	0.00E+00	0.00E+00
Al-29	2.17E+10	3.29	3.94E+02	1.76E-03	2.17E+10	3.77E+03	0.00E+00	0.00E+00
Al-30	2.34E+08	31.62	3.60E+00	1.93E-01	2.34E+08	4.07E+01	0.00E+00	0.00E+00

Radioactive Inventory inside concrete (3/5)

Isotope	Yield rate [s ⁻¹]	Rel Err. [%]	t _{1/2} (s)	λ (s ⁻¹)	A(EOB) (Bq)	C _A (EOB) (Bq/g)	A(EOB+Δt) (336 hrs) (Bq)	C _A (EOB+Δt) (336 hrs) (Bq/g)
Si-26	2.11E+08	33.33	2.23E+00	3.10E-01	2.11E+08	3.66E+01	0.0E+00	0.00E+00
Si-27	3.86E+10	2.47	4.16E+00	1.67E-01	3.86E+10	6.71E+03	0.0E+00	0.00E+00
Si-28	6.66E+12	0.28		stable				
Si-29	7.66E+13	0.06		stable				
Si-30	4.09E+12	0.09		stable				
Si-31	2.56E+12	0.08	9.44E+03	7.34E-05	2.56E+12	4.45E+05	6.7E-27	1.17E-33
P-30	7.02E+07	57.74	1.46E+02	4.74E-03	7.02E+07	1.22E+01	0.0E+00	0.00E+00
P-31	3.28E+08	26.73		stable			0.0E+00	0.00E+00
P-32	4.68E+08	22.36	1.23E+06	5.63E-07	1.01E+08	1.76E+01	5.1E+07	8.89E+00
P-33	1.40E+08	40.82	2.19E+06	3.17E-07	1.80E+07	3.12E+00	1.2E+07	2.13E+00
S-32	2.57E+08	30.15		stable				
S-33	1.67E+10	1.68		stable				
S-34	9.34E+09	5.01		stable				
S-35	1.74E+09	11.30	7.55E+06	9.185E-08	6.77E+07	1.18E+01	6.1E+07	1.05E+01
S-36	2.54E+08	29.36		stable				
S-37	3.30E+08	9.88	3.03E+02	2.288E-03	3.30E+08	5.74E+01	0.0E+00	0.00E+00
S-41	2.41E+07	35.47	2.60E+00	2.666E-01	2.41E+07	4.20E+00	0.0E+00	0.00E+00
Cl-34	3.28E+08	26.73	1.53E+00	4.541E-01	3.28E+08	5.70E+01	0.0E+00	0.00E+00
Cl-35	1.58E+10	3.85		stable				
Cl-36	2.12E+10	3.33	9.49E+12	7.302E-14	6.69E+02	1.16E-04	6.7E+02	1.16E-04
Cl-37	1.30E+10	4.26		stable				
Cl-38	1.17E+09	14.14	2.23E+03	3.102E-04	1.17E+09	2.04E+02	1.3E-154	2.21E-161
Cl-39	9.36E+07	50.00	3.37E+03	2.056E-04	9.36E+07	1.63E+01	9.7E-101	1.69E-107
Cl-40	2.34E+07	100.00	8.10E+01	8.557E-03	2.34E+07	4.07E+00	0.0E+00	0.00E+00
Ar-36	5.78E+09	6.36		stable				
Ar-37	6.79E+11	0.27	3.03E+06	2.290E-07	6.40E+10	1.11E+04	4.8E+10	8.43E+03
Ar-38	2.44E+11	0.98		stable				
Ar-39	3.67E+10	1.87	8.48E+09	8.171E-11	1.30E+06	2.25E-01	1.3E+06	2.25E-01
Ar-40	2.65E+09	7.86		stable				
Ar-41	1.38E+10	1.55	6.56E+03	1.057E-04	1.38E+10	2.40E+03	0.0E+00	0.00E+00

Radioactive Inventory inside concrete (4/5)

Isotope	Yield rate [s ⁻¹]	Rel Err. [%]	t _{1/2} (s)	λ (s ⁻¹)	A(EOB) (Bq)	C _A (EOB) (Bq/g)	A(EOB+Δt) (336 hrs) (Bq)	C _A (EOB+Δt) (336 hrs) (Bq/g)
Ar-42	1.43E+08	26.72	1.04E+09	6.68E-10	4.11E+04	7.16E-03	4.11E+04	7.15E-03
Ar-43	4.33E+08	9.08	3.22E+02	2.15E-03	4.33E+08	7.53E+01	0.00E+00	0.00E+00
Ar-45	1.26E+09	4.93	2.15E+01	3.23E-02	1.26E+09	2.18E+02	0.00E+00	0.00E+00
Ar-46	8.56E+06	70.74	8.40E+00	8.25E-02	8.56E+06	1.49E+00	0.00E+00	0.00E+00
K-35	4.25E+07	29.39	1.90E-01	3.65E+00	4.25E+07	7.40E+00	0.00E+00	0.00E+00
K-37	4.68E+07	70.71		stable				
K-38	1.66E+10	3.57	4.58E+02	1.51E-03	1.66E+10	2.89E+03	0.00E+00	0.00E+00
K-39	3.79E+11	0.80		stable				
K-40	2.63E+13	0.07		stable				
K-41	1.72E+10	3.43		stable				
K-42	1.83E+12	0.20	4.45E+04	1.56E-05	1.83E+12	3.18E+05	1.20E+04	2.09E-03
K-43	2.84E+09	6.76	8.03E+04	8.63E-06	2.77E+09	4.83E+02	8.08E+04	1.41E-02
K-44	2.14E+10	1.39	1.33E+03	5.22E-04	2.14E+10	3.72E+03	1.25E-264	2.18E-271
K-45	4.68E+07	70.71	1.04E+03	6.68E-04	4.68E+07	8.14E+00	0.00E+00	0.00E+00
K-46	1.42E+08	31.33	1.05E+02	6.60E-03	1.42E+08	2.48E+01	0.00E+00	0.00E+00
K-47	2.15E+07	41.17	1.75E+01	3.96E-02	2.15E+07	3.73E+00	0.00E+00	0.00E+00
K-48	1.92E+09	4.58	6.80E+00	1.02E-01	1.92E+09	3.33E+02	0.00E+00	0.00E+00
Ca-39	4.45E+09	7.25	8.59E-01	8.07E-01	4.45E+09	7.73E+02	0.00E+00	0.00E+00
Ca-40	6.33E+11	0.64		stable				
Ca-41	1.96E+13	0.06	3.248E+12	2.13E-13	1.80E+06	3.14E-01	1.80E+06	3.14E-01
Ca-42	8.03E+09	5.40		stable				
Ca-43	1.35E+11	0.42		stable				
Ca-44	4.08E+10	1.49		stable				
Ca-45	4.21E+11	0.21	5.13E+09	1.35E-10	2.46E+07	4.28E+00	2.46E+07	4.28E+00
Ca-46	5.62E+08	20.41		stable				
Ca-47	1.16E+09	7.46	3.92E+05	1.77E-06	6.21E+08	1.08E+02	7.32E+07	1.27E+01
Ca-48	1.45E+09	12.70		stable				
Ca-49	3.78E+10	0.66	5.23E+02	1.33E-03	3.78E+10	6.58E+03	0.00E+00	0.00E+00
Ti-47	2.34E+07	100.00		stable				
V-48	2.34E+07	100.00	1.380E+06	5.02E-07	4.57E+06	7.94E-01	2.49E+06	4.33E-01
TOTAL								

Radioactive Inventory inside concrete (5/5)

Isotope	Yield rate [s ⁻¹]	Rel Err. [%]	t _{1/2} (s)	λ (s ⁻¹)	A(EOB) (Bq)	C _A (EOB) (Bq/g)	A(EOB+Δt) (336 hrs) (Bq)	C _A (EOB+Δt) (336 hrs) (Bq/g)
V-49	4.68E+07	70.71	1.04E+10	6.66E-11	1.35E+03	2.34E-04	1.35E+03	2.34E-04
V-50	1.64E+08	37.80		stable				
V-51	2.34E+08	31.62		stable				
V-52	7.02E+07	57.74	2.25E+02	3.09E-03	7.02E+07	1.22E+01	0.00E+00	0.00E+00
Cr-50	3.04E+08	27.74		stable				
Cr-51	1.73E+09	9.48	2.39E+06	2.90E-07	2.03E+08	3.53E+01	1.43E+08	2.49E+01
Cr-52	3.21E+09	8.54		stable				
Cr-53	6.32E+09	2.76		stable				
Cr-54	1.03E+09	14.23		stable				
Cr-55	7.54E+07	53.76	2.10E+02	3.30E-03	7.54E+07	1.31E+01	0.00E+00	0.00E+00
Mn-52	8.90E+08	16.22	4.83E+05	1.43E-06	4.11E+08	7.15E+01	7.24E+07	1.26E+01
Mn-53	7.95E+09	5.42	1.81E+12	3.84E-13	1.32E+03	2.29E-04	1.32E+03	2.29E-04
Mn-54	3.15E+10	2.25	2.70E+07	2.57E-08	3.47E+08	6.04E+01	3.37E+08	5.85E+01
Mn-55	2.45E+10	3.06		stable				
Mn-56	1.43E+10	1.75	9.28E+03	stable	1.43E+10	2.49E+03	8.51E-30	1.48E-36
Mn-57	2.24E+08	21.19	9.28E+03	7.47E-05	2.24E+08	3.89E+01	1.33E-31	2.31E-38
Mn-58	3.27E+06	28.84	3.00E+00	2.31E-01	3.27E+06	5.69E-01	0.00E+00	0.00E+00
Fe-53	5.35E+08	20.53	5.11E+02	1.36E-03	5.35E+08	9.30E+01	0.00E+00	0.00E+00
Fe-54	2.21E+10	3.26		stable				
Fe-55	1.46E+12	0.23	8.61E+07	8.05E-09	5.07E+09	8.82E+02	5.02E+09	8.73E+02
Fe-56	1.61E+11	1.22		stable				
Fe-57	2.55E+13	0.06		stable				
Fe-58	5.45E+11	0.34		stable				
Fe-59	3.50E+10	1.06	3.85E+06	1.80E-07	2.62E+09	4.56E+02	2.11E+09	3.67E+02
Co-56	2.30E+10	4.51	6.68E+06	1.04E-07	1.01E+09	1.75E+02	8.89E+08	1.55E+02
TOTAL					3.435E+13	5.974E+06	5.792E+10	1.007E+04

After 6 months
C_A ≈ 1.2 kBq/g

After 1 yr
C_A ≈ 0.8 kBq/g

Cu-OFE heat sink BD activation

reference case: $E_p=70$ MeV, 52.5 kW

($I_p= 4.6816E+15$ s⁻¹)

5 days beam time

2 weeks cooling

(time slot taken as reference for SPES target removal with remote controlled system). Possible intervention inside the A6 room

MCNPX calcs

Radioactive Inventory inside Cu-OFE mat (1/5)

Isotope	Yield rate [s ⁻¹]	Rel Err. [%]	t _{1/2} (s)	λ (s ⁻¹)	A(EOB) (Bq)	C _A (EOB) (Bq/g)	A(EOB+Δt) (336 hrs) (Bq)	C _A (EOB+Δt) (336 hrs) (Bq/g)
H-1	1.325E+13	0.39		stable			0.00E+00	0.00E+00
H-2	3.321E+14	0.06		stable			0.00E+00	0.00E+00
H-3	1.179E+14	0.12	3.89E+08	1.78E-09	9.08E+10	2.34E+07	9.06E+10	2.34E+07
He3	2.397E+13	0.17		stable				
He4	5.259E+13	0.13		stable				
He5	2.198E+13	0.16	7.60E-22	9.12E+20	2.20E+13	5.67E+09	0.00E+00	0.00E+00
He6	3.801E+13	0.13	8.06E-01	8.60E-01	3.80E+13	9.80E+09	0.00E+00	0.00E+00
He7	1.046E+13	0.23	2.90E-21	2.39E+20	1.05E+13	2.70E+09	0.00E+00	0.00E+00
He8	1.803E+12	0.53	1.19E-01	5.82E+00	1.80E+12	4.65E+08	0.00E+00	0.00E+00
He9	6.447E+10	2.69	1.00E-22	6.93E+21	6.45E+10	1.66E+07	0.00E+00	0.00E+00
Li-3	4.263E+11	1.26	7.60E-23	9.12E+21	4.26E+11	1.10E+08	0.00E+00	0.00E+00
Li-4	1.838E+12	0.57	7.60E-23	9.12E+21	1.84E+12	4.74E+08	0.00E+00	0.00E+00
Li-5	4.423E+12	0.41	1.00E-99	6.93E+98	4.42E+12	1.14E+09	0.00E+00	0.00E+00
Li-6	5.152E+12	0.42		stable				
Li-7	6.923E+12	0.37		stable				
Li-8	3.920E+12	0.45	8.38E-01	8.27E-01	3.92E+12	1.01E+09	0.00E+00	0.00E+00
Li-9	2.906E+12	0.41	1.78E-01	3.89E+00	2.91E+12	7.49E+08	0.00E+00	0.00E+00
Li-10	5.525E+11	0.92	3.80E-22	1.82E+21	5.52E+11	1.42E+08	0.00E+00	0.00E+00
Li-11	7.959E+08	24.25	8.50E-03	8.15E+01	7.96E+08	2.05E+05	0.00E+00	0.00E+00
Be-5	2.477E+10	4.71	7.60E-23	9.12E+21	2.48E+10	6.38E+06	0.00E+00	0.00E+00
Be-6	1.562E+12	0.57	5.00E-21	1.39E+20	1.56E+12	4.03E+08	0.00E+00	0.00E+00
Be-7	6.483E+11	1.00	4.60E+06	1.51E-07	4.08E+10	1.05E+07	3.40E+10	8.77E+06
Be-8	1.738E+12	0.66	1.00E-99	6.93E+98	1.74E+12	4.48E+08	0.00E+00	0.00E+00
Be-9	8.248E+11	1.03		stable				
Be-10	1.614E+12	0.63	4.76E+13	1.46E-14	1.01E+04	2.62E+00	1.01E+04	2.62E+00
Be-11	2.016E+11	1.61	1.38E+01	5.02E-02	6.09E+08	5.20E+07	0.00E+00	0.00E+00
Be-12	5.426E+10	2.94	2.36E-02	2.94E+01	5.43E+10	1.40E+07	0.00E+00	0.00E+00
Be-13	6.086E+08	27.74	2.70E-21	5.02E-02	6.09E+08	1.57E+05	0.00E+00	0.00E+00
B-6	1.404E+08	57.74	1.00E-22	6.93E+21	1.40E+08	3.62E+04	0.00E+00	0.00E+00
B-7	3.043E+09	12.40	3.30E-22	2.10E+21	3.04E+09	7.85E+05	0.00E+00	0.00E+00
TOTAL								

Radioactive Inventory inside Cu-OFE mat (2/5)

Isotope	Yield rate [s ⁻¹]	Rel Err. [%]	t _{1/2} (s)	λ (s ⁻¹)	A(EOB) (Bq)	C _A (EOB) (Bq/g)	A(EOB+Δt) (336 hrs) (Bq)	C _A (EOB+Δt) (336 hrs) (Bq/g)
B-8	3.563E+10	3.06	7.70E-01	9.00E-01	3.563E+10	9.18E+06	0.00E+00	0.00E+00
B-9	3.853E+10	0.00	8.40E-19	8.25E+17	3.853E+10	9.93E+06	0.00E+00	0.00E+00
B-10	1.241E+11	2.58		stable				
B-11	9.958E+10	0.00		stable				
B-12	1.026E+11	2.25	2.02E-02	3.43E+01	1.026E+11	2.65E+07	0.00E+00	0.00E+00
B-13	6.409E+10	2.70	2.70E-21	2.57E+20	6.409E+10	1.65E+07	0.00E+00	0.00E+00
B-14	6.409E+10	2.70	1.38E-02	5.02E+01	6.409E+10	1.65E+07	0.00E+00	0.00E+00
C-9	4.682E+07	100.00	1.26E-01	5.50E+00	4.682E+07	1.21E+04	0.00E+00	0.00E+00
C-10	1.217E+09	19.61	1.92E+01	3.61E-02	1.217E+09	3.14E+05	0.00E+00	0.00E+00
C-11	6.835E+09	8.93	1.22E+03	5.67E-04	6.835E+09	1.76E+06	1.59E-288	4.09E-292
C-12	4.448E+09	14.11		stable				
C-13	8.146E+09	10.01		stable				
C-14	3.886E+09	14.52	1.81E+11	3.84E-12	6.439E+03	1.66E+00	6.44E+03	1.66E+00
C-15	4.682E+07	100.00	2.45E+00	2.83E-01	4.682E+07	1.21E+04	0.00E+00	0.00E+00
C-16	1.358E+09	18.57	7.47E-01	9.28E-01	1.358E+09	3.50E+05	0.00E+00	0.00E+00
N-13	4.682E+08	31.62	5.98E+02	1.16E-03	4.682E+08	1.21E+05	0.00E+00	0.00E+00
N-14	1.873E+08	50.00		stable				
N-15	1.217E+09	31.62		stable				
N-16	1.873E+08	50.00	7.13E+00	9.72E-02	1.873E+08	4.83E+04	0.00E+00	0.00E+00
O-14	1.276E+09	6.77	7.06E+01	9.82E-03	1.276E+09	3.29E+05	0.00E+00	0.00E+00
O-15	2.516E+08	15.25	1.22E+02	5.67E-03	2.516E+08	6.49E+04	0.00E+00	0.00E+00
O-16	1.551E+09	8.16		stable				
O-17	3.102E+08	18.34		stable				
O-18	2.750E+08	14.59		stable				
O-19	2.516E+08	15.25		stable				
Ti-47	2.516E+08	15.25		stable				
Ti-48	2.750E+08	14.59		stable				
Ti-49	5.852E+07	31.62		stable				
Ti-50	1.276E+09	6.77		stable				
V-49	1.522E+08	19.61	1.04E+10	6.66E-11	4.3779E+03	1.13E+00	4.38E+03	1.13E+00
TOTAL								

Radioactive Inventory inside Cu-OFE mat (3/5)

Isotope	Yield rate [s ⁻¹]	Rel Err. [%]	t _{1/2} (s)	λ (s ⁻¹)	A(EOB) (Bq)	C _A (EOB) (Bq/g)	A(EOB+Δt) (336 hrs) (Bq)	C _A (EOB+Δt) (336 hrs) (Bq/g)
V-50	1.87E+08	50		stable				
V-51	4.68E+08	31.62		stable				
V-52	0.00E+00	0	2.25E+02	3.09E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00
V-53	0.00E+00	0	9.66E+01	7.18E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cr-50	6.55E+08	26.73		stable				
Cr-51	1.36E+09	18.57	2.39E+06	2.90E-07	1.60E+08	3.67E+05	1.12E+08	2.90E+04
Cr-52	3.23E+09	12.04		stable				
Cr-53	6.79E+09	8.3		stable				
Cr-54	1.22E+09	19.61		stable				
Cr-55	4.68E+07	100	2.10E+02	3.30E-03	4.68E+07	1.08E+05	0.00E+00	0.00E+00
Cr-56	0.00E+00	0	3.56E+02	1.94E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Mn-52	3.28E+08	37.8	4.83E+05	1.43E-06	1.51E+08	3.48E+05	2.67E+07	6.88E+03
Mn-53	6.41E+10	2.7	1.81E+12	3.84E-13	1.06E+04	2.44E+01	1.06E+04	2.74E+00
Mn-54	1.02E+11	2.14	2.70E+07	2.57E-08	1.13E+09	2.60E+06	1.09E+09	2.82E+05
Mn-55	3.55E+10	3.63		stable				
Mn-56	2.18E+10	4.64	9.28E+03	7.47E-05	2.18E+10	5.01E+07	1.29E-29	3.33E-33
Mn-57	3.04E+09	12.4	8.54E+01	8.12E-03	3.04E+09	7.00E+06	0.00E+00	0.00E+00
Mn-58	1.40E+08	57.74	3.00E+00	2.31E-01	1.40E+08	3.23E+05	0.00E+00	0.00E+00
Mn-59	0.00E+00	0	4.60E+00	1.51E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Mn-60m	0.00E+00	0	1.77E+00	3.92E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Fe-53	6.09E+08	27.74	5.11E+02	1.36E-03	6.09E+08	1.40E+06	0.00E+00	0.00E+00
Fe-54	5.43E+10	2.94		stable				
Fe-55	2.01E+11	1.53	8.61E+07	8.05E-09	6.98E+08	1.61E+06	6.91E+08	1.78E+05
Fe-56	1.56E+12	0.55		stable				
Fe-57	6.24E+11	0.87		stable				
Fe-58	1.79E+11	1.62		stable				
Fe-59	2.46E+10	4.36	3.85E+06	1.80E-07	1.84E+09	4.23E+06	1.48E+09	3.82E+05
Fe-60	2.95E+09	12.6	8.26E+13	8.39E-15	1.07E+01	2.46E-02	1.07E+01	2.76E-03
Fe-61	1.87E+08	50	3.59E+02	1.93E-03	1.87E+08	4.31E+05	0.00E+00	0.00E+00
Fe-62	4.68E+07	100	6.80E+01	1.02E-02	4.68E+07	1.08E+05	0.00E+00	0.00E+00
TOTAL								

Radioactive Inventory inside Cu-OFE mat (4/5)

Isotope	Yield rate [s ⁻¹]	Rel Err. [%]	t _{1/2} (s)	λ (s ⁻¹)	A(EOB) (Bq)	C _A (EOB) (Bq/g)	A(EOB+Δt) (336 hrs) (Bq)	C _A (EOB+Δt) (336 hrs) (Bq/g)
Fe-63	0.00E+00	0.00	6.10E+00	1.14E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Co-55	7.96E+08	24.25	6.31E+04	1.10E-05	7.89E+08	1.81E+06	1.34E+03	3.46E-01
Co-56	5.52E+11	0.92	6.68E+06	1.04E-07	2.42E+10	5.57E+07	2.14E+10	5.51E+06
Co-57	2.90E+12	0.40	2.35E+07	2.95E-08	3.68E+10	8.46E+07	3.55E+10	9.16E+06
Co-58	3.37E+12	0.37	6.12E+06	1.13E-07	1.61E+11	3.70E+08	1.40E+11	3.61E+07
Co-59	4.02E+12	0.34		stable				
Co-60	1.86E+12	0.58	1.66E+08	4.17E-09	3.35E+09	7.70E+06	3.33E+09	8.59E+05
Co-61	4.05E+11	1.10	5.94E+03	1.17E-04	4.05E+11	9.31E+08	2.03E-50	5.23E-54
Co-62	5.82E+10	3.34	9.00E+01	7.70E-03	5.82E+10	1.34E+08	0.00E+00	0.00E+00
Co-63	2.14E+10	4.67	2.74E+01	2.53E-02	2.14E+10	4.93E+07	0.00E+00	0.00E+00
Co-64	7.02E+08	31.61	3.00E-01	2.31E+00	7.02E+08	1.61E+06	0.00E+00	0.00E+00
Ni-56	2.34E+09	14.14	5.10E+05	1.36E-06	1.04E+09	2.39E+06	2.01E+08	5.18E+04
Ni-57	6.45E+10	2.69	1.28E+05	5.41E-06	5.82E+10	1.34E+08	8.39E+07	2.16E+04
Ni-58	1.80E+12	0.51		stable				
Ni-59	1.04E+13	0.54	2.40E+12	2.89E-13	1.30E+06	2.99E+03	1.30E+06	3.35E+02
Ni-60	3.62E+13	2.15		stable				
Ni-61	2.19E+13	8.22		stable				
Ni-62	1.64E+13	50.47		stable				
Ni-63	2.73E+12	66.53	3.16E+09	2.20E-10	2.59E+08	5.96E+05	2.59E+08	6.68E+04
Ni-64	1.26E+12	1190.58		stable				
Ni-65	7.05E+10	89.47	9.06E+03	7.65E-05	7.05E+10	1.62E+08	4.64E-30	1.20E-33
Cu-58	9.36E+07	70.71	3.20E+00	2.16E-01	9.36E+07	2.15E+05	0.00E+00	0.00E+00
Cu-59	4.31E+10	3.30	8.15E+01	8.50E-03	4.31E+10	9.92E+07	0.00E+00	0.00E+00
Cu-60	2.70E+12	0.42	1.42E+03	4.87E-04	2.70E+12	6.20E+09	2.32E-244	5.97E-248
Cu-61	2.85E+13	0.13	1.20E+04	5.78E-05	2.85E+13	6.55E+10	1.28E-17	3.30E-21
Cu-62	5.87E+13	0.10	5.84E+02	1.19E-03	5.87E+13	1.35E+11	0.00E+00	0.00E+00
Cu-63	2.56E+14	0.04		stable				
Cu-64	1.59E+13	0.20	4.57E+04	1.52E-05	1.59E+13	3.66E+10	1.73E+05	4.45E+01
Cu-65	1.04E+14	0.07		stable			0.00E+00	0.00E+00
Cu-66	4.52E+11	0.90	3.07E+02	2.26E-03	4.52E+11	1.04E+09	0.00E+00	0.00E+00
TOTAL								

Radioactive Inventory inside Cu-OFE mat (5/5)

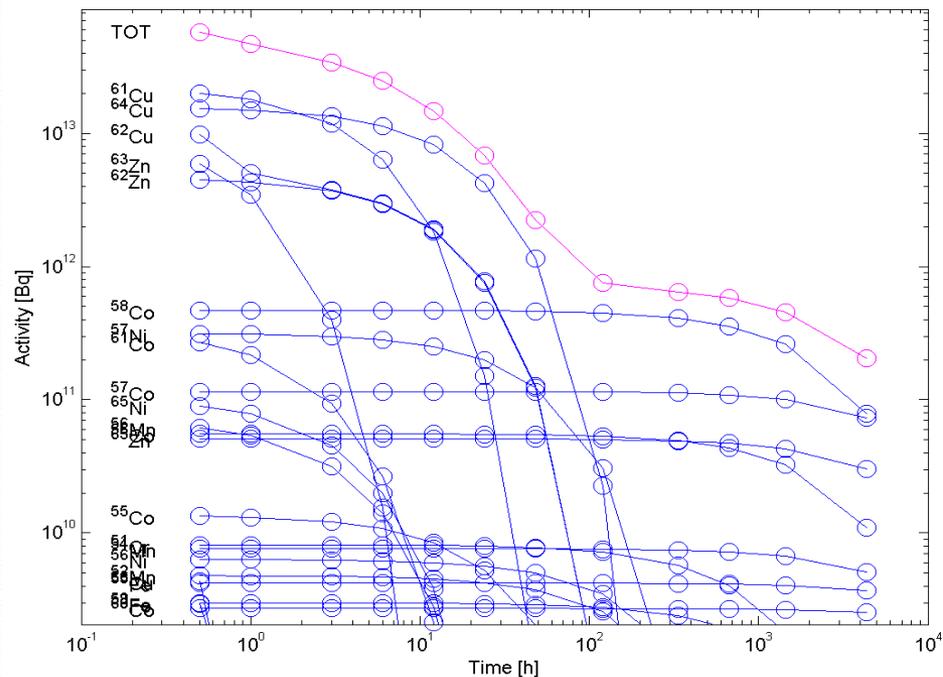
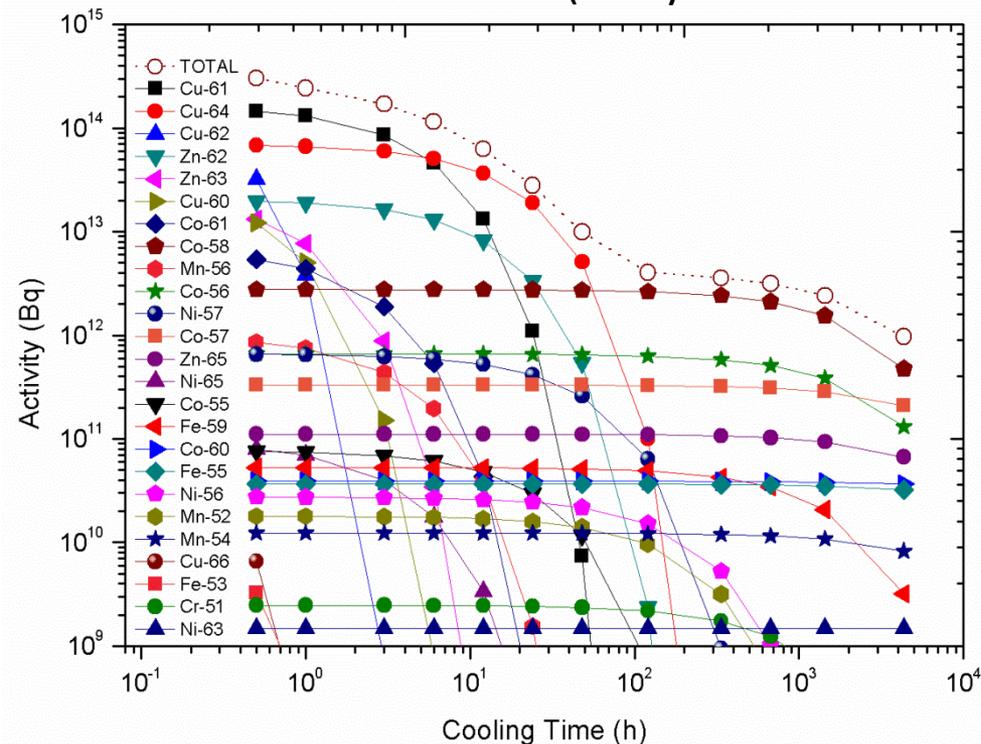
Isotope	Yield rate [s ⁻¹]	Rel Err. [%]	t _{1/2} (s)	λ (s ⁻¹)	A(EOB) (Bq)	C _A (EOB) (Bq/g)	A(EOB+Δt) (336 hrs) (Bq)	C _A (EOB+Δt) (336 hrs) (Bq/g)
Zn-59	0.00E+00	0.00	1.800E-01	3.85E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Zn-60	5.15E+09	9.53	1.428E+02	4.85E-03	5.15E+09	1.33E+06	0.00E+00	0.00E+00
Zn-61	2.81E+11	1.31	8.910E+01	7.78E-03	2.81E+11	7.24E+07	0.00E+00	0.00E+00
Zn-62	5.08E+12	0.31	3.307E+04	2.10E-05	5.08E+12	1.31E+09	4.96E+01	1.28E-02
Zn-63	9.01E+12	0.24	2.308E+03	3.00E-04	9.01E+12	2.32E+09	1.59E-145	4.10E-149
Zn-64	1.25E+13	0.19					0.00E+00	0.00E+00
Zn-65	4.06E+12	0.35	2.110E+07	3.28E-08	5.72E+10	2.91E+11	5.49E+10	1.42E+07
TOTAL					2.120E+14	3.461E+11	3.839E+11	9.898E+07

Cu-OFE: main residual activity contributors vs. time

MCNPX-FLUKA comparison (preliminary calculation on a simplified BD configuration)

The largest contributors to Cu-OFE BD residual activity

(5 days beam time $E_p=70$ MeV, $750 \mu\text{A}$)



At shorter cooling times (e.g. 0.5 h)

^{61}Cu 48.05% **MCNPX**

At longer cooling times (e.g. 6 months)

^{58}Co 49.26% **MCNPX**

At shorter cooling times (e.g. 0.5 h)

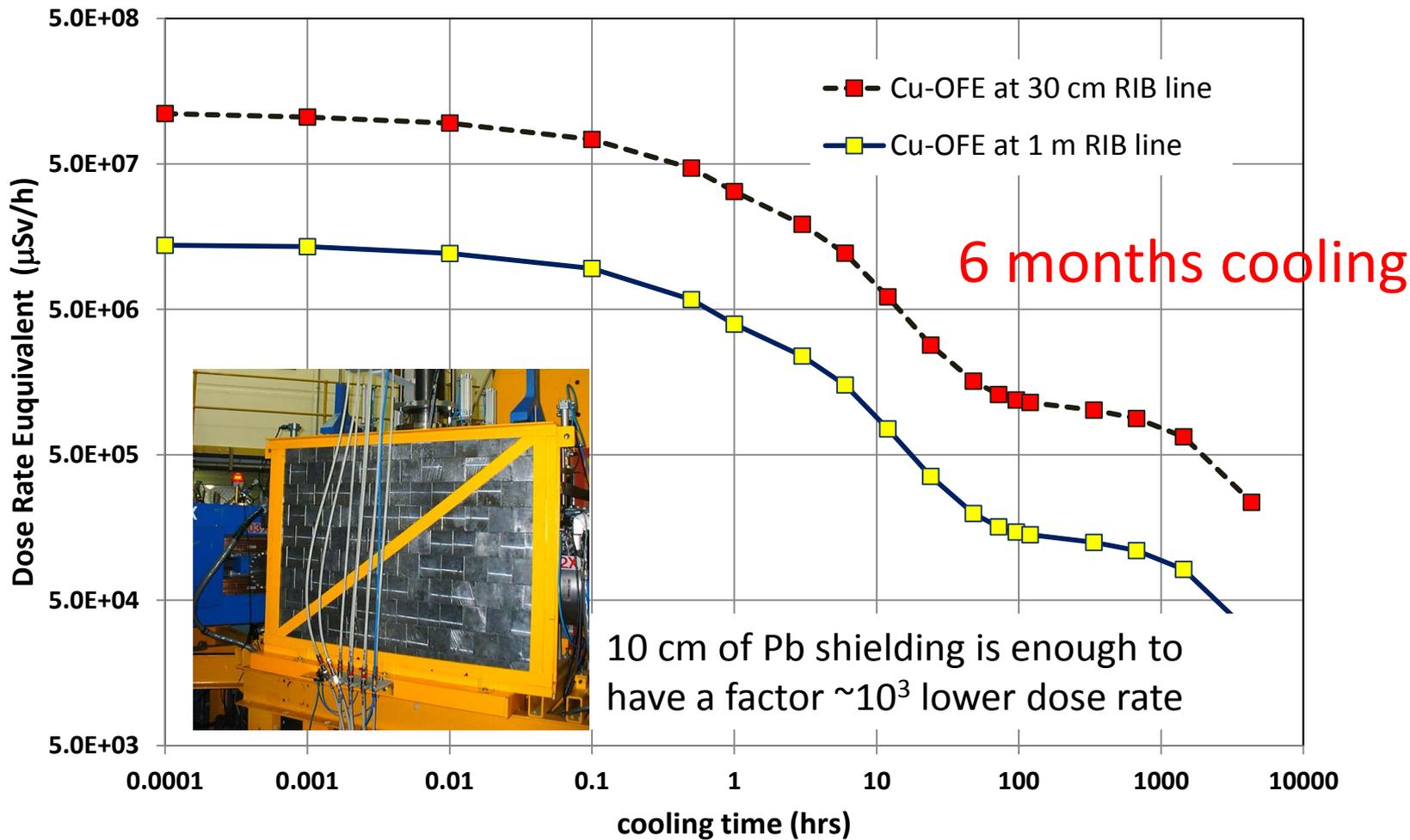
^{61}Cu 34.95% **FLUKA**

At longer cooling times (e.g. 6 months)

^{58}Co 38.68% **FLUKA**

Cu-OFE Residual Activity dose rates expected (naked BD) (5 days irradiation). When SPES BD decommissioning could start...

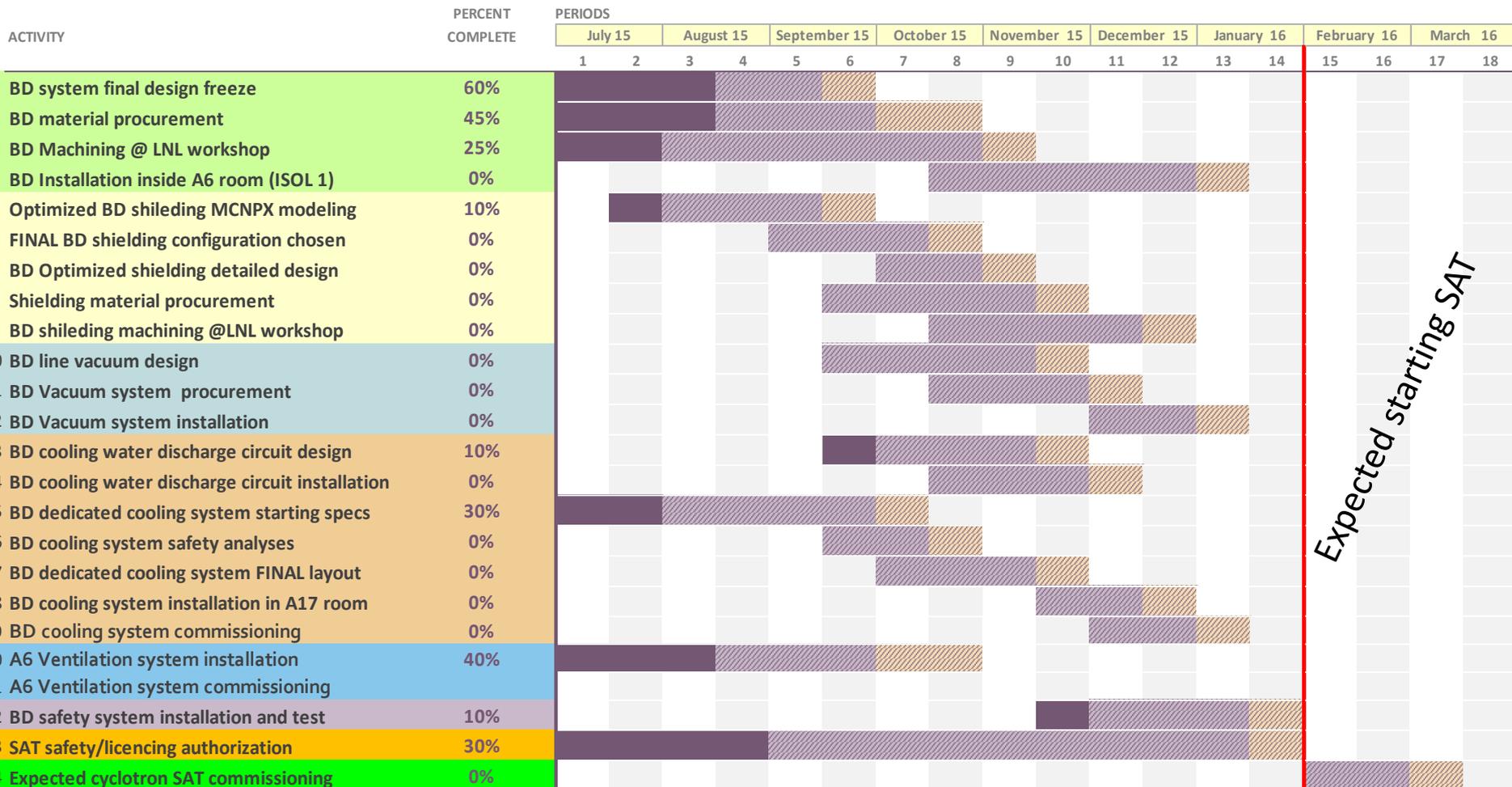
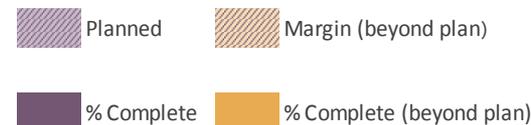
Residual Gamma Dose-Rate Equivalent distribution along RIB beam line inside bunker
Cu OFE vs. BD, 5 days beam time $E_p=70$ MeV



Expected BD time schedule for cyclotron commissioning

SPES BD Project Activities Plan

Period Highlight: 21



Expected starting SAT

Thanks for your attention!