
CERN
HSE
Occupational Health & Safety
and Environmental Protection unit

# RP studies for CNGS dismantling

Elzbieta Nowak, Claudia Ahdida, Christelle Saury, Helmut Vincke, Renaud Mouret

Meeting with STI-TCD, RP-RW, RP-AS
02.07.2020

# Outline

Status of the dismantling preparatory studies and investigations:

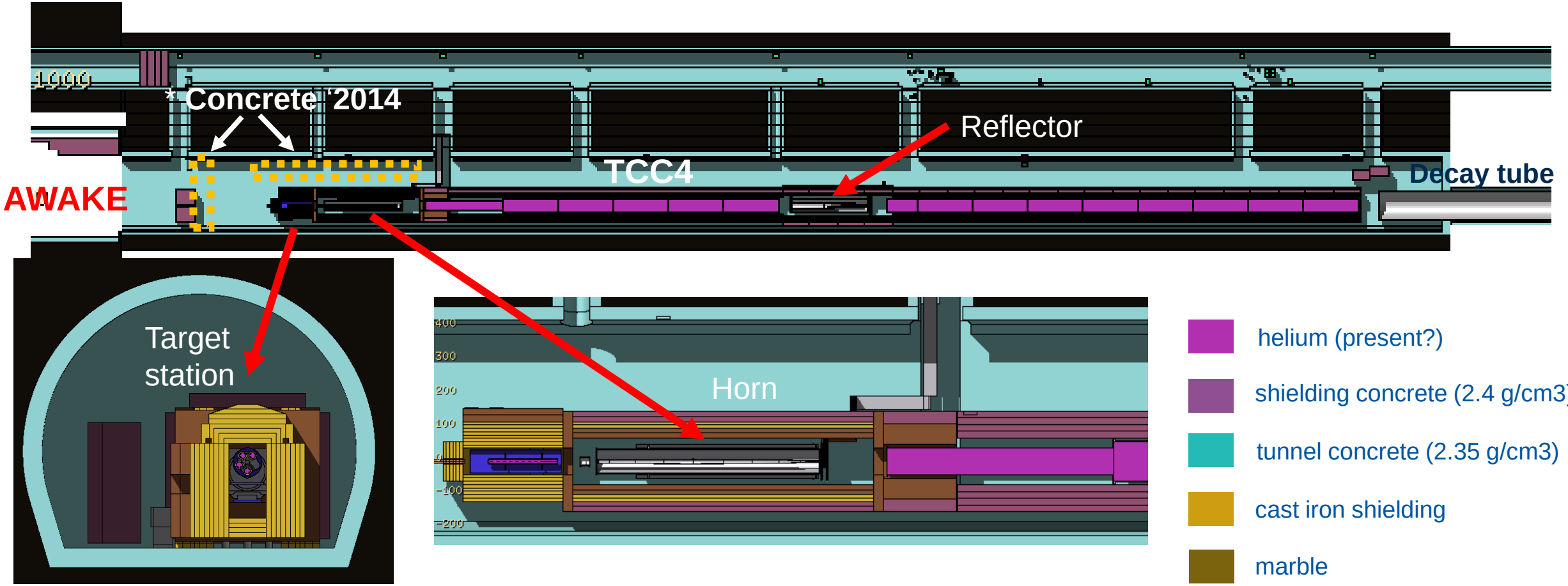
- Optimization of the FLUKA CNGS model: verification of the equipment materials, simulation settings

- MC FLUKA studies on residual dose rates in the CNGS area and separately for its most activated components
  - Hot spot dose rates of the target, horn and reflector
  - Residual dose rates in the CNGS tunnel and comparison to the survey performed on 16/06/2020
  - Residual dose rate in the dismantled CNGS area in a view of future radiological classification (not discussed in this presentation)
  - MC FLUKA and ACTIWIZ for radionuclide inventory of the CNGS beam line equipment including its shielding in view of their transport and waste disposal actions (RP-CS/RW) (not discussed in this presentation)

- Concrete composition analysis → gamma spec analysis of three samples (wall, floor, shielding) – sampling on 16/06/2020
  - Preliminary conclusions on the missing trace elements

- Ongoing/future:
  - 'SESAME' for evaluation of the dose rates during dismantling process for selected equipment or parts of the shielding
  - 'SESAME' for the target/horn/shielding design
  - Residual dose rates estimates for remaining shielding: marble, iron and the helium pipe

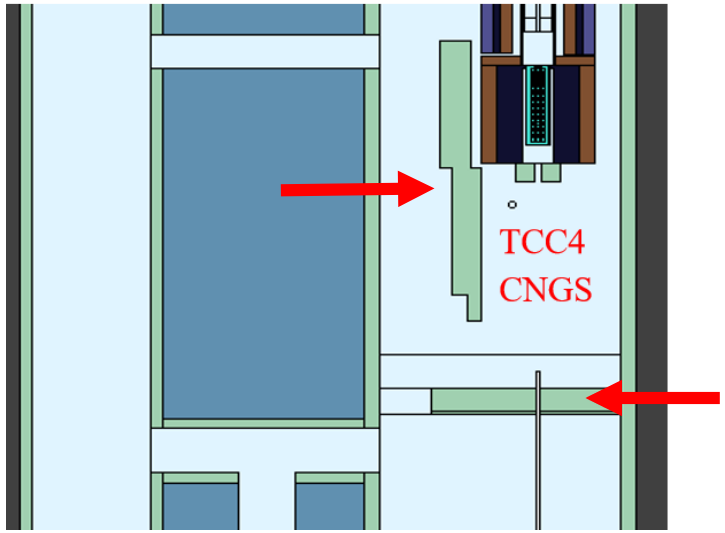
# CNGS tunnel and beam line equipment – FLUKA model



# Changes in CNGS area for start of AWAKE

## Main changes after 2012:

- Separation wall between AWAKE and CNGS area (does not allow usage of crane at the moment) - 2014
- Additional concrete shielding installation in 2014 ~17.5m
- Removal of collimator (boron nitride, surrounded by GG20 wall) – 1,5 mSv/h at 40 cm in 2016; 20 cm Ø opening to CNGS target

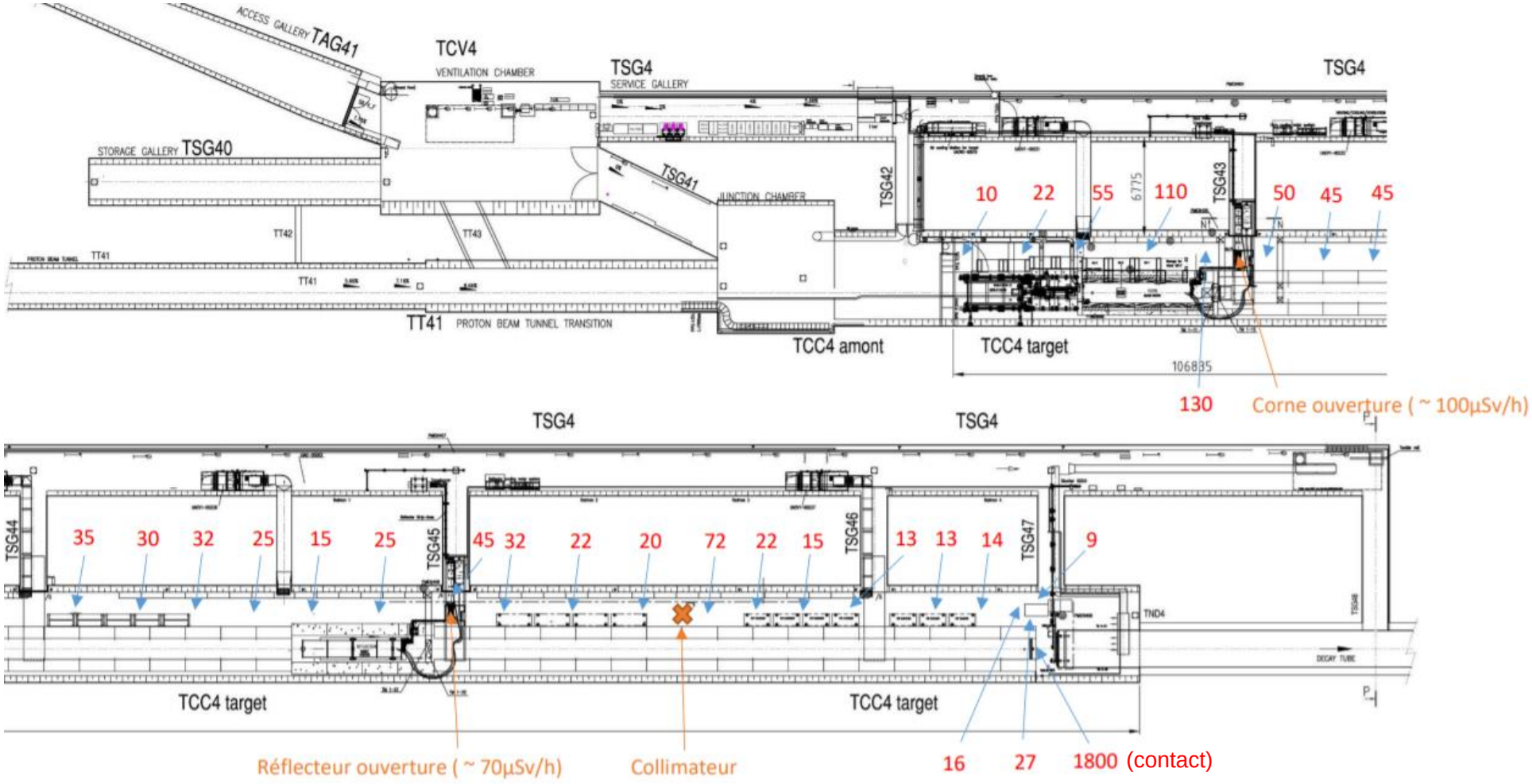




# MC FLUKA study assumptions/settings

- ✓ Irradiation profile: CNGS beam operation runs and stop (2008-2012)
  - average POT : 4e19/year, **1.8e20 POT over 5 years of operation**
- ✓ Cooling times:
  - 1st survey 26.07.2015
  - 2nd survey 04.2019
  - 03.2020 – first visit to CNGS
  - 09.2021
  - **06.2022 early start date for CNGS dismantling**
  - **01.2025 latest date for CNGS dismantling**
  - 3rd survey 16.06.2020
- ✓ EMF thresholds production/transport: 100 keV for e-/e+, 10 keV for photons
- ✓ Neutron transport down to thermal energies
- ✓ Particle transport threshold energy: 3 MeV for prompt dose studies
- ✓ Magnetic field in horn/reflector, magfld.f routine
- ✓ LOW-MAT cards for carbon target parts (rods, tube)
- ✓ Horn, reflector and target materials changes

# Survey 16/06/2020- residual dose rate measurements



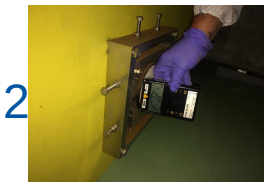

- ✓ Measurements along the TCC4 tunnel, each 4 m
- ✓ Vertical position :of the detector: 1m60
- ✓ Horizontally: half distance between the shielding and the wall
- ✓ Opening of the horn and reflector: at 1m

* 30/06 new measurements for the collimator:

1. 4.2 mSv/h at the contact /tube
2. 280 uSv/h at contact (other side)
   28 uSv/h at 40cm

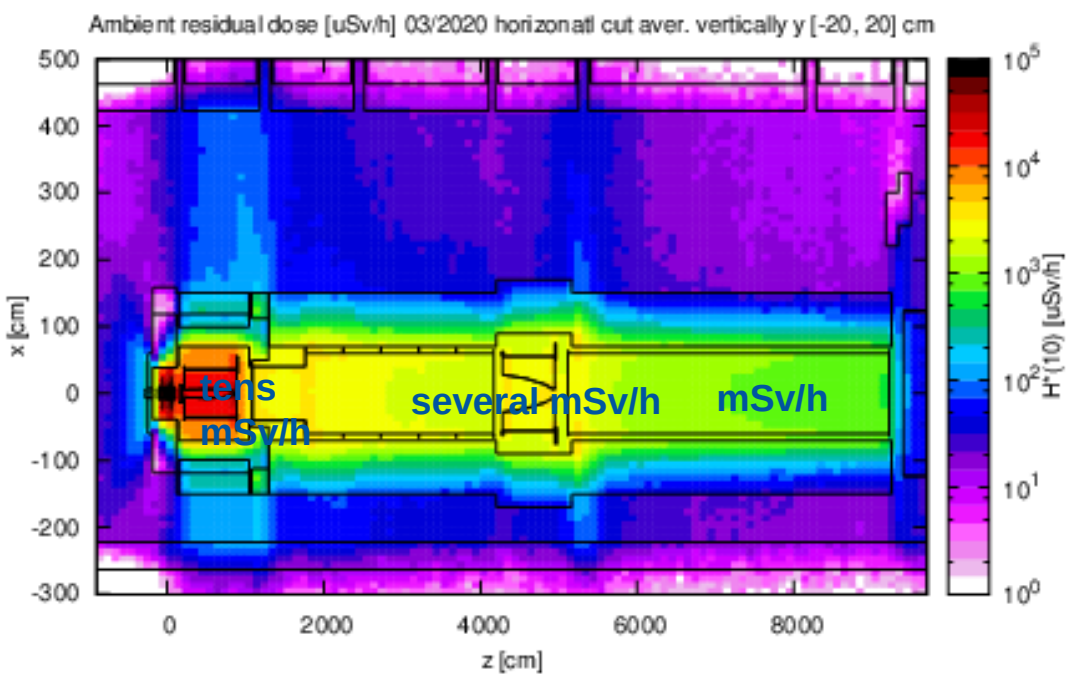
1

2

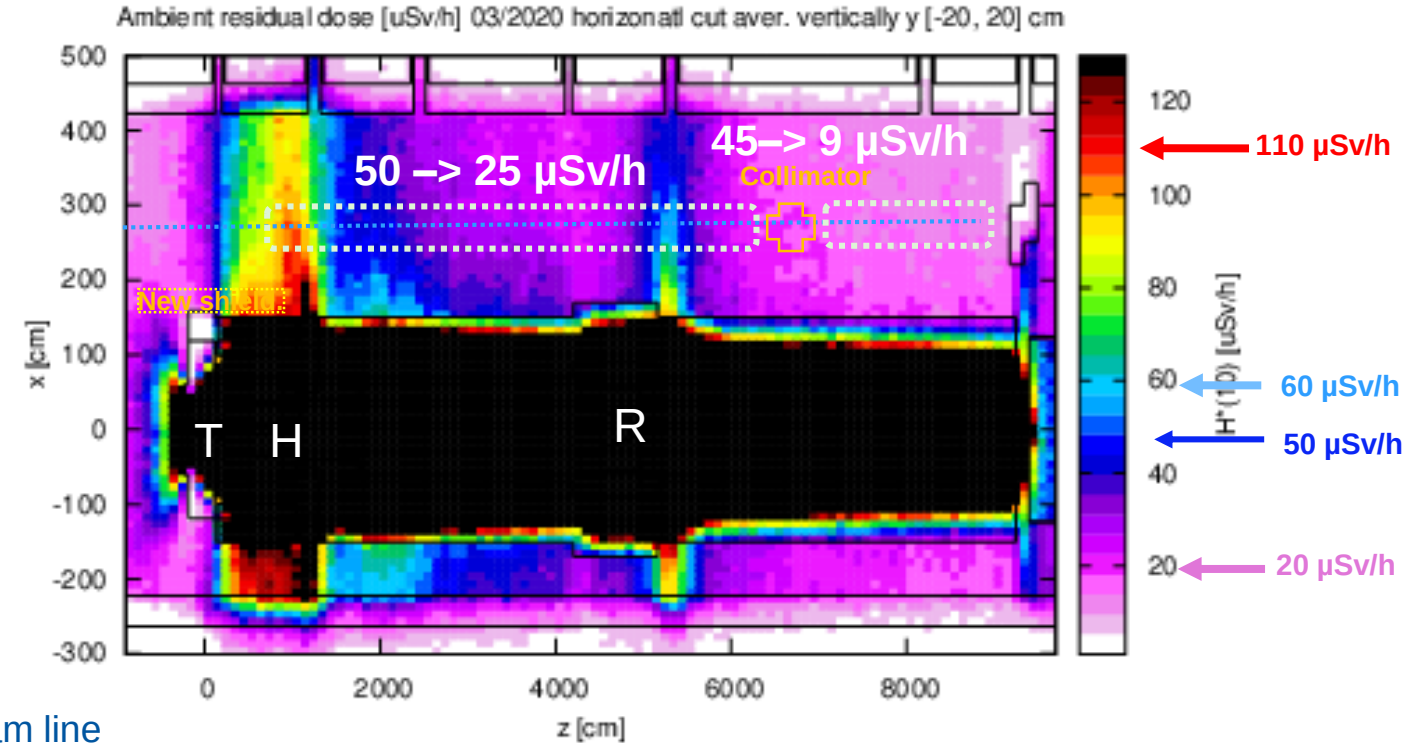


# Comparison of FLUKA assessed ambient dose rates in CNGS tunnel vs measurements, 7.3 y of cooling down

Log scale

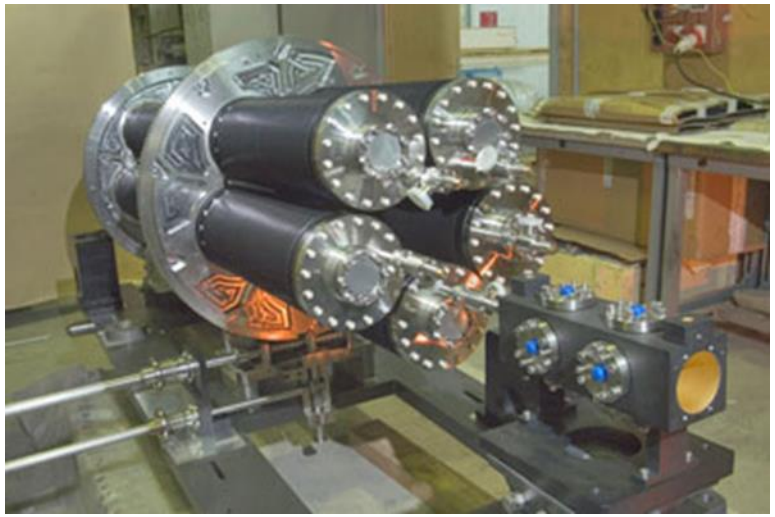


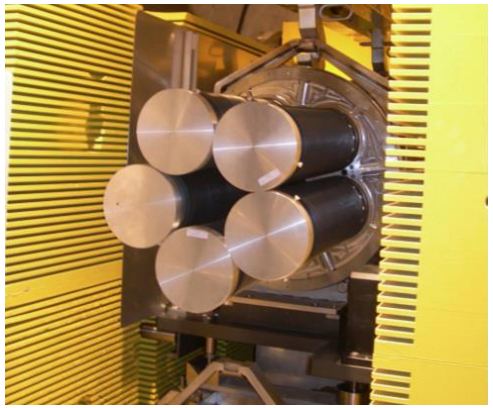

Lin scale



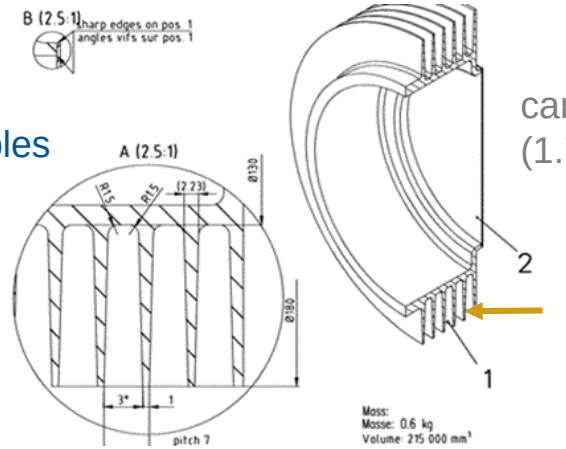

- ✓ Very good agreement for the dose rates along the beam line
- ✓ Target and partially horn surrounding can't be directly compared – additional shielding installed for AWAKE in 2014
- ✓ Old collimator vicinity – (measured: 72 µSv/h) – not included in the FLUKA model
- ✓ Closure of the second helium pipe, the downstream window of a high dose rate 1.8 mSv, to be verified by future studies
- ✓ Air contribution to the dose level is not representative as being exchanged

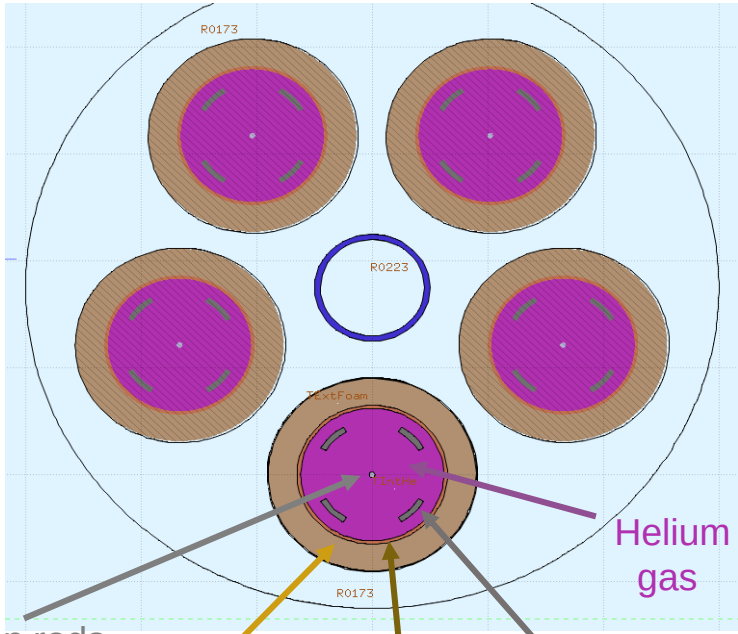
# Target – MC FLUKA model of the target revolver





✓ Target revolver, rotating discs, tables to be treated/analysed together for dismantling, transport and storage?



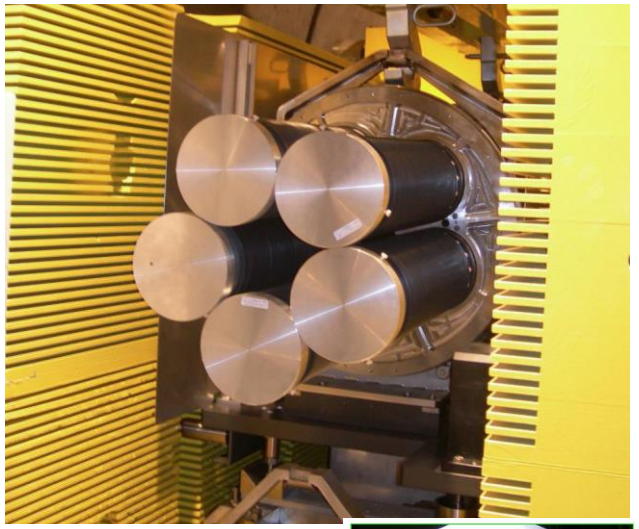



# Target – ambient residual dose rates – MC FLUKA estimates

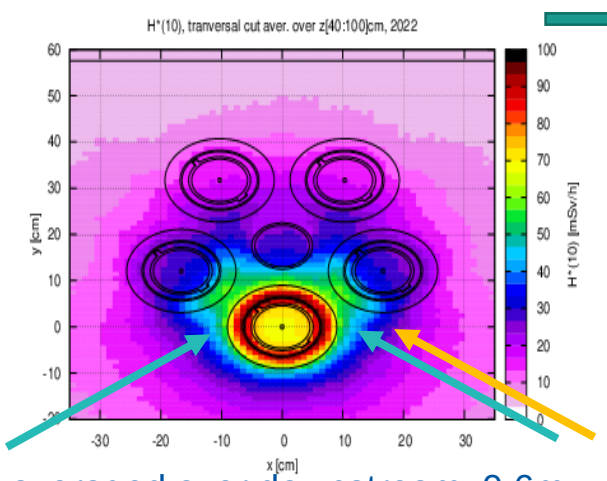
| Cooling time | Dose rate at 4cm from the HOT SPOT in x and y (aver. long. over downstream 60cm) | Dose rate at 10cm – from the HOT SPOT In x and y (aver. long. over downstream 60cm) | Dose rate at 10cm averaged over first 90 cm for max. value in x and y |
|---|---|---|---|
| 2020 | 70-75 mSv/h | 50-55 mSv/h F~2-2.5 | 20 mSv/h |
| 2022 | 35-40 mSv/h | 25-30 mSv/h | 12 mSv/h |
| 2025 | 20 mSv/h | 12-15 mSv/h | 6 mSv/h |

✓ **Dose rates estimates for the target revolver as a unit, with all the five tubes kept together**

✓ **Rotating discs, tables are not included**

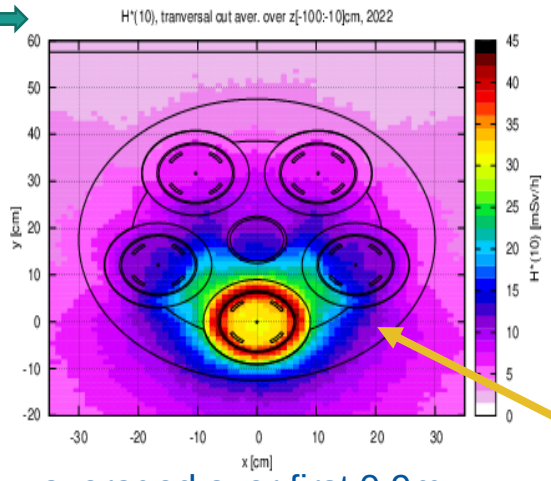


2022




@4cm

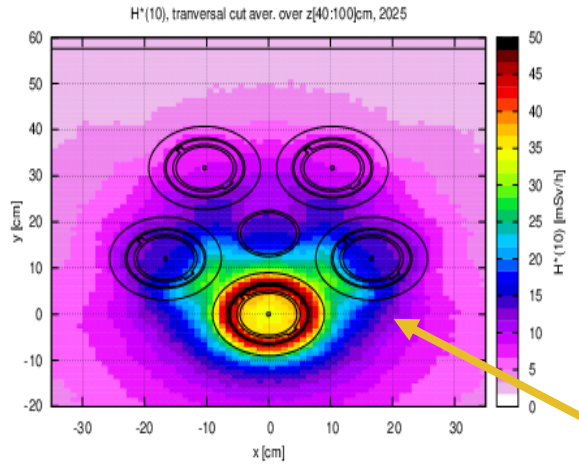
averaged over downstream 0.6m




@10cm

averaged over first 0.9m

2025




@10cm

averaged over downstream 0.6m

# Target – integrated specific and total activity

✓ 5 Al-5083 tubes, density: 2.7g/cm3

| | Bq/g | Bq |
|---|---|---|
| 2022 | 7.10E+05 | 1.42E+10 |
| 2025 | 5.69E+05 | 1.14E+10 |

Reactions on Al, Mg

H-3 Al (94%, Mg 4.4%)

Na-22 Al (85%, Mg 14.5%)

✓ 5 external 'radiators': Al-5083 (H111):AIR (1/3:2/3 in volume), density: 0.9 g/cm3

| | A [Bq/g] | A tot [Bq] |
|---|---|---|
| 2022 | 6.05E+05 | 6.44E+10 |
| 2025 | 4.83E+05 | 5.14E+10 |

H-3 Al (94%, Mg 4.4%)

Na-22 Al (86%, Mg 13.6%)

✓ 5 Carbon targets, density: 1.76 g/cm3, 13 rods per one tube, (5/4 mm in diameter)

| | A [Bq/g] | Atot [Bq] |
|---|---|---|
| 2022 | 2.48E+07 | 2.44E+09 |
| 2025 | 2.10E+07 | 2.06E+09 |

H-3

✓ Carbon supports in 5 tubes: graphite, density 1.81 g/cm3

| | A [Bq/g] | Total A [Bq] |
|---|---|---|
| 2.02E+03 | 1.35E+06 | 4.45E+09 |
| 2.03E+03 | 1.14E+06 | 3.76E+09 |

H-3

## Eg: Al radiator tube

| pure beta | Radionuclide | Halflife | Bq/g | |
|---|---|---|---|---|
| 1 | H-3 | 12.33y | 2.66E+06 | 88.05% |
| 0 | Na-22 | 2.6y | 3.51E+05 | 11.62% |
| 1 | Fe-55 | 2.73y | 7.32E+03 | 0.24% |
| 1 | C-14 | 8.59y | 5.51E+02 | 0.02% |
| 0 | Co-60 | 5.27y | 5.33E+02 | 0.02% |
| 0 | Ti-44 | 60.00y | 3.01E+02 | 0.01% |

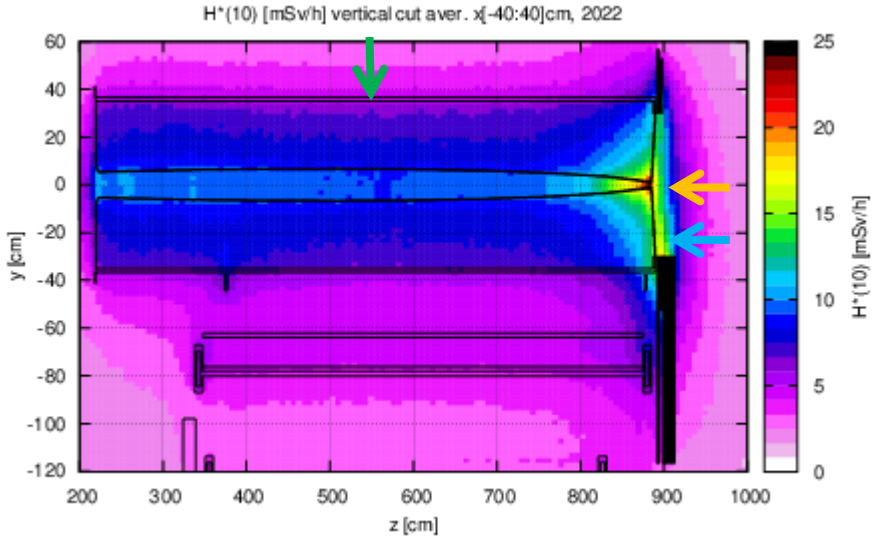
## Integrated over all 5 tubes

| | Bq/g | |
|---|---|---|
| | 2022 | 2025 |
| C rods | 2.46E+07 | 2.08E+07 |
| C support | 1.35E+06 | 1.14E+06 |
| Al tube | 7.10E+05 | 5.69E+05 |
| radiator | 6.05E+05 | 4.83E+05 |
| TOTAL A [Bq] | 9.33E+10 | 7.52E+10 |

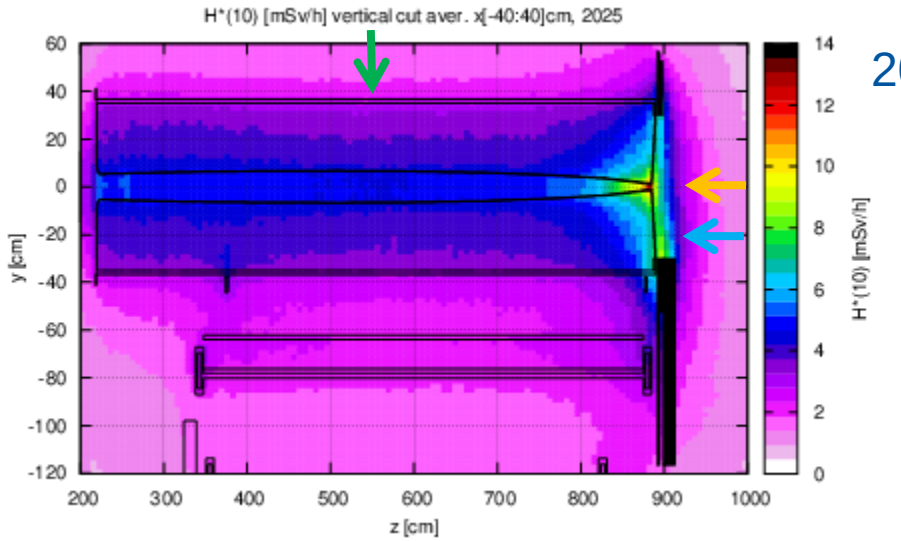
# Horn – residual dose rates

| Cooling time | HOT SPOT dose rates on the axis at 10cm ← | HOT SPOT dose rate at 10cm – max near stripline ← | HOT SPOT dose rate at 10cm radially, side surface ← |
|---|---|---|---|
| 2020 | 25-30 mSv/h | 20-30 mSv/h | 7-8 mSv/h |
| 2022 | 17 mSv/h | 15 mSv/h | 4-5 mSv/h |
| 2025 | 6 mSv/h | 3 mSv/h | 2 mSv/h |

✓ Stripline: to be treated/analysed separately for dismantling, transport and storage?



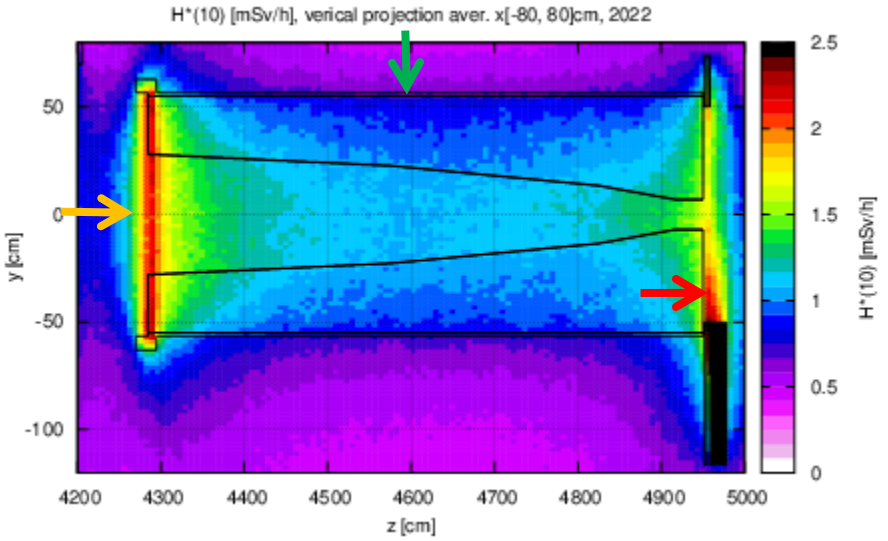

2022

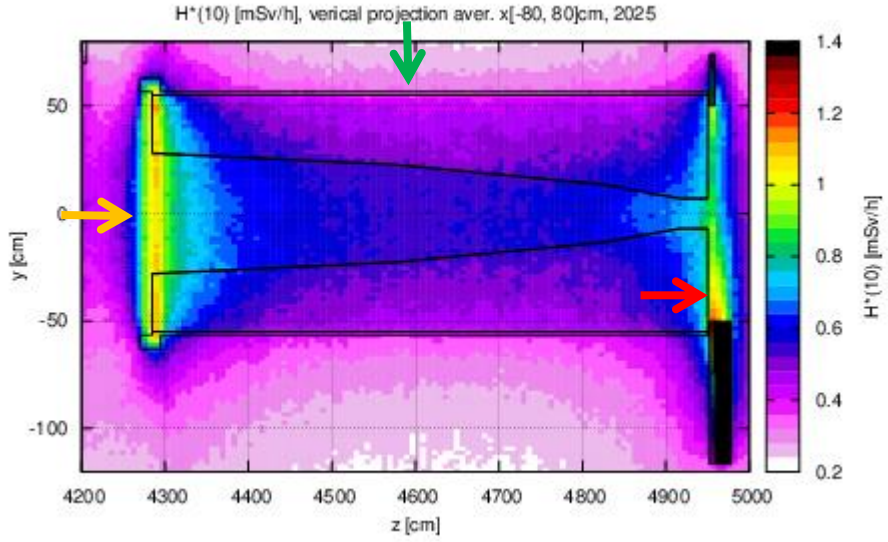



2025

# Reflector - residual dose rates

| Cooling time | HOT SPOT dose rates at 10 cm, from the entrance flange → | Dose rate at 10 cm from stripline/cables → | HOT SPOT dose rate at 10 cm radially, side surface (4m center) → |
|---|---|---|---|
| 2020 | 5 mSv/h | 4 mSv/h | 1-1.5 mSv./h |
| 2022 | 2 mSv/h | 2 mSv/h | 0.7 mSv/h |
| 2025 | 0.9 mSv/h | 1 mSv/h | 0.4 mSv/h |




✓ Stripline: to be treated/analysed separately for dismantling/transport/storage?

# Horn and reflector specific and total activity

## HORN

- ✓ Material: Al-6082, density: 2.7g/cm3
- ✓ Striplines not included

### SPECIFIC and TOTAL ACTIVITY

| | 2022 | 2025 |
|---|---|---|
| Spec. A [Bq/g] | 7.14E+06 | 5.74E+06 |
| **Total A [Bq]** | 9.19E+10 | 7.39E+10 |

| pure beta | Radionuclide | Halflife | Bq/g | |
|---|---|---|---|---|
| 1 | H-3 | 12.33y | 6.23E+06 | 89.61% |
| 0 | Na-22 | 2.6y | 6.92E+05 | 9.96% |
| 1 | Fe-55 | 2.73y | 2.39E+04 | 0.34% |
| 1 | C-14 | 8.59y | 1.10E+03 | 0.02% |
| 0 | Co-60 | 5.27y | 1.09E+03 | 0.02% |
| 0 | Ti-44 | 60.00y | 6.66E+02 | 0.01% |

2022

**Al-6082**

| | |
|---|---|
| Al: | 0.9625 |
| Si: | 0.01 |
| Mg: | 0.009 |
| Mn: | 0.007 |
| Fe: | 0.005 |
| Cr: | 0.0025 |
| Zn: | 0.002 |
| Cu: | 0.001 |
| Ti: | 0.001 |

Reactions on Al, Mg

Al- 92%, Mg - 7.5%

## REFLECTOR

Material: Al-6082, density: 2.7g/cm3

- ✓ Striplines not included

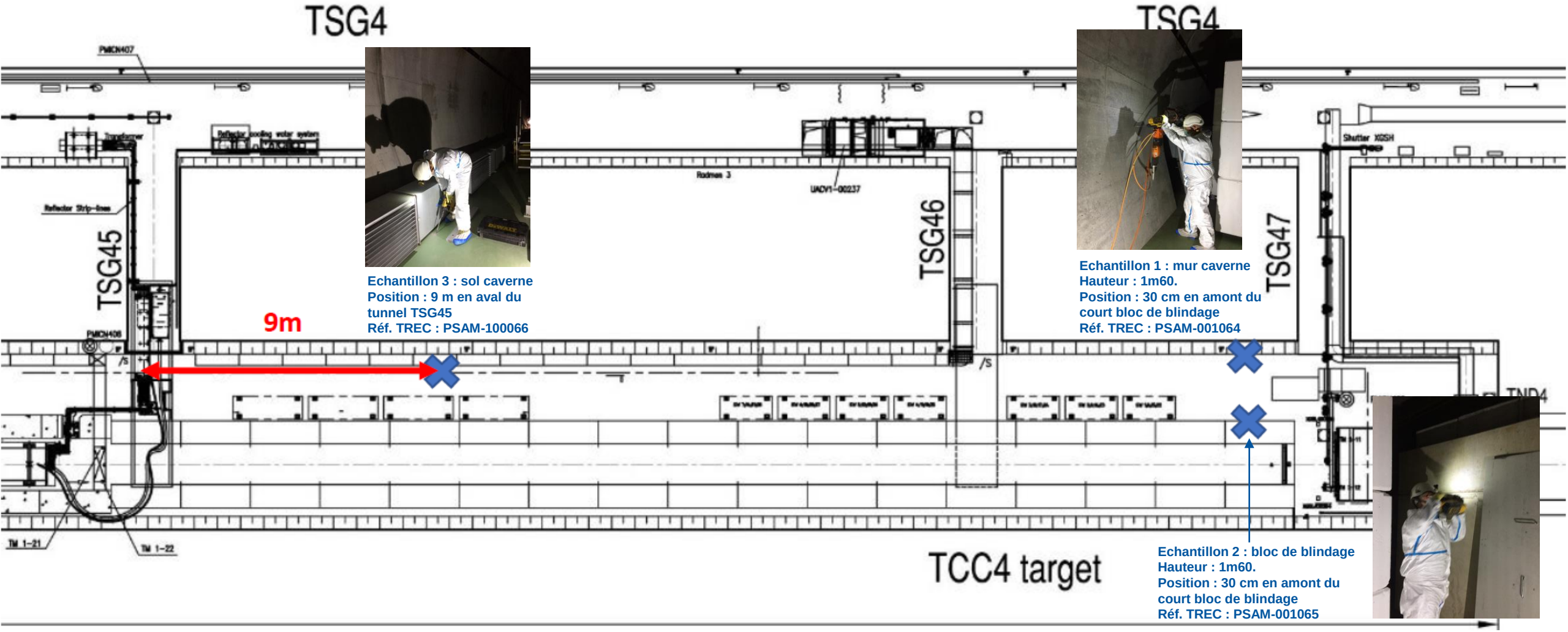
### SPECIFIC and TOTAL ACTIVITY

| | 2022 | 2025 |
|---|---|---|
| Spec. A [Bg/g] | 2.35E+05 | 2.19E+05 |
| **Total A [Bq]** | 1.87E+10 | 1.51E+10 |

| pure beta | Radionuclide | Halflife | Bq/g | |
|---|---|---|---|---|
| 1 | H-3 | 12.33y | 2.08E+05 | 93.73% |
| 0 | Na-22 | 2.6y | 1.35E+04 | 6.06% |
| 1 | Fe-55 | 2.73y | 3.53E+02 | 0.16% |
| 1 | C-14 | 8.59y | 2.63E+01 | 0.01% |
| 0 | Co-60 | 5.27y | 1.91E+01 | 0.01% |
| 0 | Ti-44 | 60.00y | 1.38E+01 | 0.01% |

2022

# Concrete sampling for gamma spectroscopy analysis 16/06/2020






Echantillon 3 : sol caverne
Position : 9 m en aval du tunnel TSG45
Réf. TREC : PSAM-100066



Echantillon 1 : mur caverne
Hauteur : 1m60.
Position : 30 cm en amont du court bloc de blindage
Réf. TREC : PSAM-001064



Echantillon 2 : bloc de blindage
Hauteur : 1m60.
Position : 30 cm en amont du court bloc de blindage
Réf. TREC : PSAM-001065

# CNGS concrete composition assumed for MC FLUKA and ACTIWIZ studies + preliminary conclusions from the gamma spec reports

## Tunnel wall and floor

- Density: 2.35 g/cm3

| | |
|---|---|
| ALUMINUM | 0.0211 |
| CALCIUM | 0.239 |
| CARBON | 0.043 |
| COBALT | 0.000004 |
| EUROPIUM | 4E-07 |
| HYDROGEN | 0.00562 |
| IRON | 0.0126 |
| MAGNESIUM | 0.0151 |
| OXYGEN | 0.482 |
| POTASSIUM | 0.00833 |
| SILICON | 0.162 |
| SODIUM | 0.00446 |
| SULFUR | 0.00414 |
| TITANIUM | 0.00173 |

## Shielding blocks

- Density: 2.42 g/cm3

| | |
|---|---|
| ALUMINUM | 0.034 |
| CALCIUM | 0.044 |
| CARBON | 0.001 |
| HYDROGEN | 0.01 |
| IRON | 0.014 |
| MAGNESIUM | 0.002 |
| OXYGEN | 0.529 |
| POTASSIUM | 0.013 |
| SILICON | 0.337 |
| SODIUM | 0.016 |

- ✓ Good agreement for Na-22 – the main contributor to the activity/LL among gamma emitters
- ✓ Eu and Co traces content should be revised
- ✓ Cs traces should be included

- ✓ Eu and Co and Cs traces should be included
- ✓ Si content should be revised – Na-22 disagreement with a factor of 2.8

→ Other analysis eg. XRF to verify content of more abundant elements, if possible

# Ongoing and future studies/actions

- Ongoing and future studies:
  - After the gamma spectroscopy - tunnel and shielding concrete composition  should be refined – new simulations will be needed
  - ‘Sesame’ evaluations: dose rates during dismantling process, shielding design for the target/horn transport
  - Further nuclide inventory evaluations for iron and marble shielding
  - Dose rates and nuclide inventory study for the decay pipe
- Possibly measure high dose rate positions (may need support from EN-EA/EN-STI in how to access inside of target, inside of horns etc.)
- Where possible, perform swipe tests to assess contamination levels (here again support from EN-EA/EN-STI needed)
- Questions:
  - How the target will undergo dismantling/transport/storage? With holders, tables, rotating discs together..? How to carry out future FLUKA and ACTIWIZ studies?
  - How the reflector/horns will be dismantled/transported/stored – together with the strip line, the fixation part staying in a direct contact?

THANK YOU FOR YOUR ATTENTION


www.cern.ch

# Gamma spectroscopy results – shielding/block sample

| | | | BLOCK SAMPLE | | | | |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| | | | FLUKA/ACTIWIZ | | | gamma spec report | |
| Bq/g | pure beta | Radionuclide | Halflife | A[Bq/g] | | A[Bq/g] | F-A/GAMMA |
| | 1 | H-3 (b) | 12.33y | 8.96E+01 | | | |
| | 0 | Na-22 | 2.6y | 1.66E+01 | | 6.01 | 2.757 |
| | 1 | Ar-39 | 269.00y | 5.65E-01 | | | |
| | 1 | Fe-55 | 2.73y | 1.18E+01 | | | |
| | 0 | Co-60 | 5.27y | 2.48E-07 | | 7.82E-01 | - |
| | 0 | Eu-152 | 13.537y | 0 | | 1.52 | - |
| | 0 | Eu-154 | 5.95y | 0 | | 0.149 | - |
| | 1 | C-14 | 8.59y | 1.32E-01 | | | |
| | 0 | Si-32 | 153y | 2.79E-03 | | | |
| | 1 | P-32 | 14.268d | 2.79E-03 | | | |
| | 0 | Mn-54 | 312.1d | 6.15E-02 | | 4.06E-02 | 1.515 |
| | 0 | Ti-44 | 60.00y | 6.32E-03 | | | |
| | EC | V-49 | 329d | 2.04E-02 | | | |
| | 0 | K-42 | 12.3h | 5.71E-03 | | | |
| | EC | Ca-41 | 1.03×105 y | 2.80E-02 | | | |
| | 0 | Sc-44 | 3.97h | 6.32E-03 | | | |
| Sum | | | | 1.19E+02 | | | |

*gamma spec: Cs-134: 0.064 Bq/g

*First, preliminary conclusions:*

✓ *Eu and Co and Cs traces should be included*

✓ *Si content should be revised*

# Gamma spectroscopy results – tunnel wall sample

| | | WALL SAMPLE | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | FLUKA/ACTIWIZ | gamma spec report | | |
| Bq/g | pure beta | Radionuclide | Halflife | A[Bq/g] | A[Bq/g] | -A/GAMMA | |
| | 1 | H-3 (b) | 12.33y | 2.17E+01 | | | |
| | 0 | Na-22 | 2.6y | 2.32E+00 | 2.51 | 0.93 | |
| | 1 | Ar-39 | 269.00y | 2.65E-01 | | | |
| | 1 | Fe-55 | 2.73y | 4.34E+00 | | | |
| | 0 | Co-60 | 5.27y | 3.94E-01 | 1.09 | 0.36 | |
| | 0 | Eu-152 | 13.537y | 7.97E-02 | 1.94 | 0.04 | |
| | 0 | Eu-154 | 5.95y | 1.31E-02 | 0.169 | 0.08 | |
| | 1 | C-14 | 8.59y | 2.93E-02 | | | |
| | 0 | Si-32 | 153y | 1.91E-03 | | | |
| | 1 | P-32 | 14.268d | 1.91E-03 | | | |
| | 0 | Mn-54 | 312.1d | 1.41E-02 | | | |
| | 0 | Ti-44 | 60.00y | 3.14E-03 | | | |
| | EC | V-49 | 329d | 4.21E-03 | | | |
| | 0 | K-42 | 12.3h | 7.24E-03 | | | |
| | EC | Ca-41 | 1.03×105 y | 7.58E-02 | | | |
| | 0 | Sc-44 | 3.97h | 3.14E-03 | | | |
| Sum | | | | 2.92E+01 | | | |

*gamma spec:

Cs-143: 0.108 Bq/g

*First, preliminary conclusions:*

✓ *Good agreement for Na-22*

✓ *Eu and Co traces should be revised*

✓ *Cs traces should be included*

# Gamma spectroscopy results – tunnel floor sample

| | | | | FLUKA/ACTIWIZ | | gamma spec report | |
|---|---|---|---|---|---|---|---|
| Bq/g | pure beta | Radionuclide | Halflife | A[Bq/g] | | A[Bq/g] | F-A/GAMMA |
| | 1 | H-3 (b) | 12.33y | 2.98E+01 | | | |
| | 0 | Na-22 | 2.6y | 3.21E+00 | | 4.82 | 0.666 |
| | 1 | Ar-39 | 269.00y | 3.82E-01 | | | |
| | 1 | Fe-55 | 2.73y | 6.60E+00 | | | |
| | 0 | Co-60 | 5.27y | 6.15E-01 | | 0.652 | 0.943 |
| | 0 | Eu-152 | 13.537y | 1.24E-01 | | 1.93 | 0.064 |
| | 0 | Eu-154 | 5.95y | 2.08E-02 | | 0.179 | 0.116 |
| | 1 | C-14 | 8.59y | 4.13E-02 | | | |
| | 0 | Si-32 | 153y | 2.62E-03 | | | |
| | 1 | P-32 | 14.268d | 2.62E-03 | | | |
| | 0 | Mn-54 | 312.1d | 2.03E-02 | | 0.0381 | 0.533 |
| | 0 | Ti-44 | 60.00y | 4.22E-03 | | | |
| | EC | V-49 | 329d | 5.87E-03 | | | |
| | 0 | K-42 | 12.3h | 9.97E-03 | | | |
| | EC | Ca-41 | 1.03×105 y | 1.18E-01 | | | |
| | 0 | Sc-44 | 3.97h | 4.22E-03 | | | |
| Sum | | | | 4.09E+01 | | | |

*gamma spec:

Cs-134:

0.125 Bq/g

*First, preliminary conclusions:*

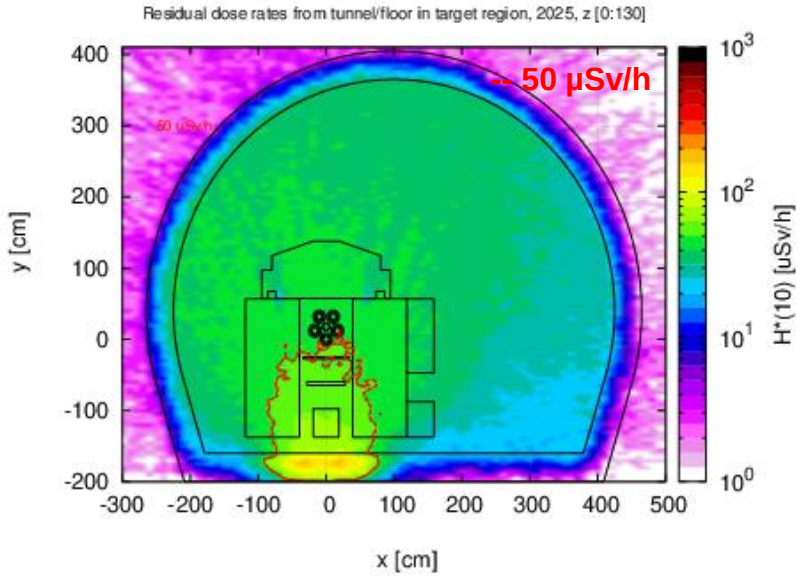
✓ *Eu traces should be revised*

✓ *Cs traces should be included*

# Floor and wall residual dose evaluated for 2025

- The most activated:
  - floor below the horn (not shielded)
  - floor below the target (40cm of GG20)
  - floor below the reflector (not shielded)
  - floor below the helium part I (not shielded)
  - ceiling above the horn (30cm of GG20)

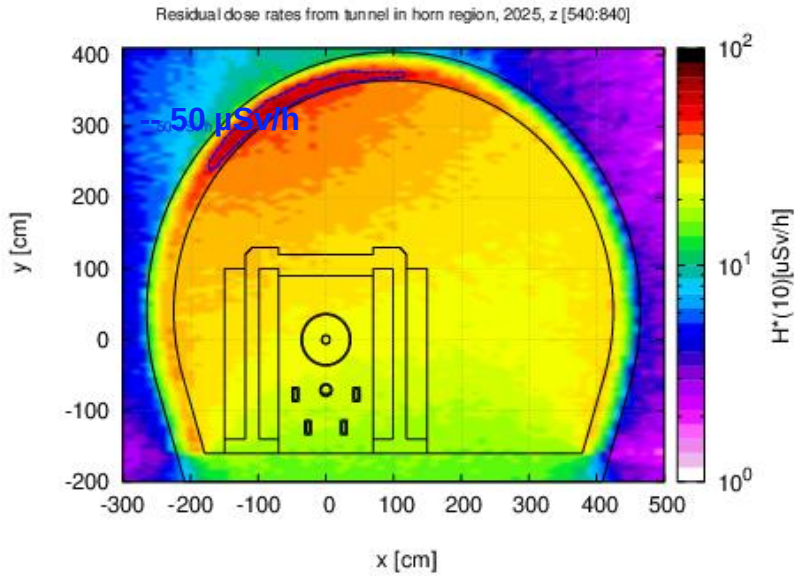
- Preliminary-
To be revised and compared to the refined concrete composition!




Below the limit of 50 µSv/h
Simple Controlled Radiation Area

For the floor contribution shielding would need to suppress >100 µSv/h to arrive at <50 µSv/h (>4cm of iron or >12cm of concrete)
*Co-60

Wall contribution around horn,
floor activation neglected

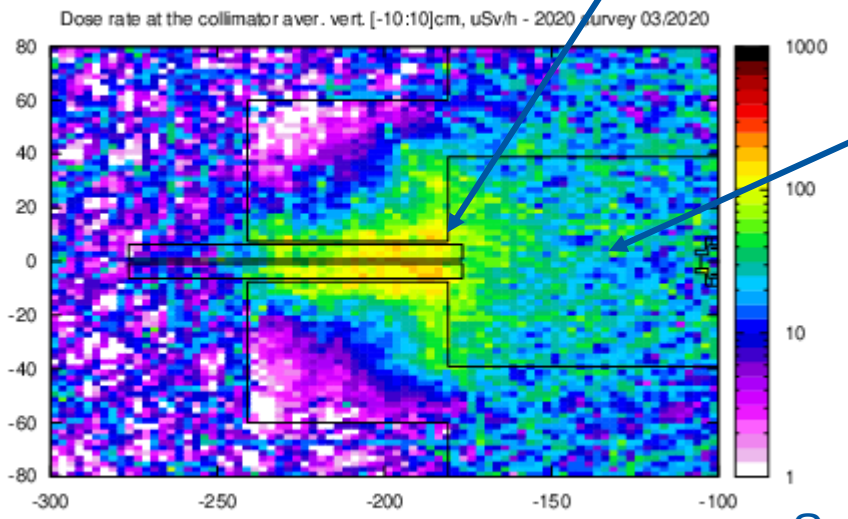



Simple Controlled Radiation Area
with horn floor shielded to <50 µSv/h (from ~900 µSv/h)
(>35 cm of concrete or >11cm of iron)
*Co-60

# Collimator measurements on 30/06/2020

03/2020

At the contact
100-120 µSv/h




At 40cm
~30-40 µSv/h

µSv/h

280 µSv/h measured at the contact
28 µSv/h at 40 cm distance

- ✓ 7mm aperture
- ✓ Iron block around
- ✓ No metallic structure/frame on both sides of the block
- ✓ No metallic structure around BN
- ✓ No simulation of the primary beam/hallo on the collimator

# TARGET – residual dose rates – hot spot

- ✓ **Max. residual dose rate distributions for 7.3 years of cooling (03.2020)**
- ✓ **No shielding around the target (open target)**

Max. above 100 mSv/h at 4cm (1*)
Accessible: 70-75 mSv/h at 4cm (2*)
50-60 mSv/h at 10 cm (max.) (3*)