# RCS ACTIVATION STUDIES

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REVISED

# Outline

- Airborne Activity
- Residual Ambient Dose Equivalent
- Residual nuclides

# Limits for airborne activity

- Swiss directive HSK-R-41.
- 0.2 mSv maximum annual Effective Dose for inhalation.
- For CERN 10 μSv $y^{-1}$ for all the installations.
- 1 μSv $y^{-1}$ is assumed for the RCS only.
- Conversion coefficients Bq->Sv from CERN-SC-2008-001-IE-TN.
- Reference population group: 240 m from the stack (ISOLDE stack).
- Outdoor and indoor exposures are weighted according to occupancy factors.

# Methods

- Beam intensities: 8.56E12 $^{6}$He/s, 2.62E12 $^{18}$Ne/s
- Loss assumptions:
  - 30% at injection
  - 3.8%($^{6}$He) and 1.4%($^{18}$Ne) by decay
  - 16%($^{6}$He) and 24%($^{18}$Ne) by RF capture and acceleration
- FLUKA simulations: n, p, $\pi^{\pm}$ track length spectrum scoring in the air tunnel.
- Folding of particle track-length spectra with isotope production cross sections:

$$Y_i = \sum_{j,k} n_j \int \sigma_{ijk}(E)\Lambda_k(E)dE$$

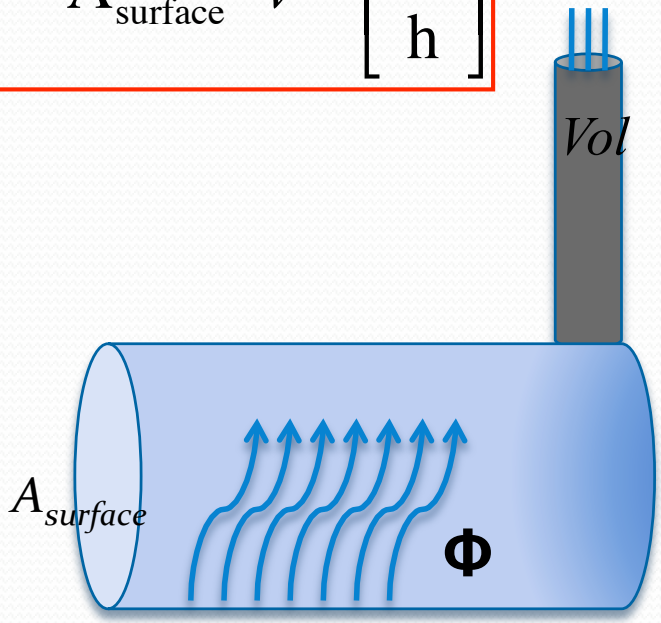
  - $n_j$ = atomic concentration (per cm$^3$) of the element $j$ in the material
  - $\sigma_{ijk}$ = cumul. cross section for the nuclide $i$ in the reaction of a particle of type $k$ and energy $E$ with a nucleus of element $j$
  - $\Lambda_k$= track length sum of hadrons of type $k$ and energy $E$

# Methods

## Laminar flow model

$$F = A_{surface} \cdot v \qquad \left[\frac{m^3}{h}\right]$$

$$A_{sat} = \int_{E_{min}}^{E_{max}} \varphi \cdot \sigma \cdot \rho \frac{N_{Avogadro}}{A} \cdot dE$$




$$A_{released} = F \cdot A_{sat}(1 - e^{-t_{irr}\lambda})e^{-T_{decay}\lambda}$$

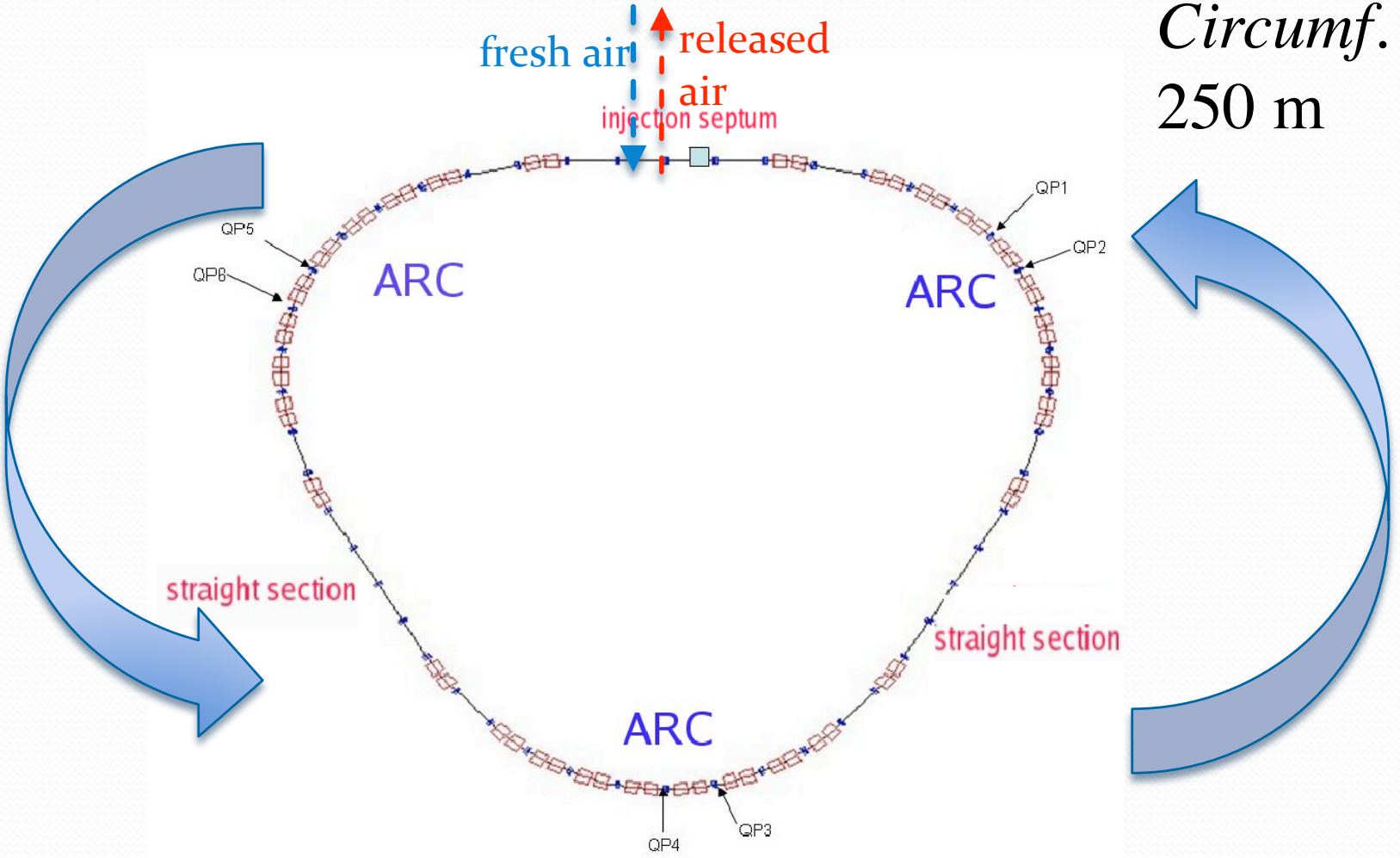
$$t_{irr} = \frac{l}{v} = \frac{l}{F} \cdot A_{surface}$$

$$R = \frac{nuclides}{s}$$

$$A_{released} = \frac{F}{A_{surface} \cdot l} \cdot R(1 - e^{-\frac{l}{F} \cdot A_{surface}\lambda})e^{-\frac{Vol}{F}\lambda}$$

# RCS ventilation systems

In the calculations it has been assumed to use 1 ventilation system.

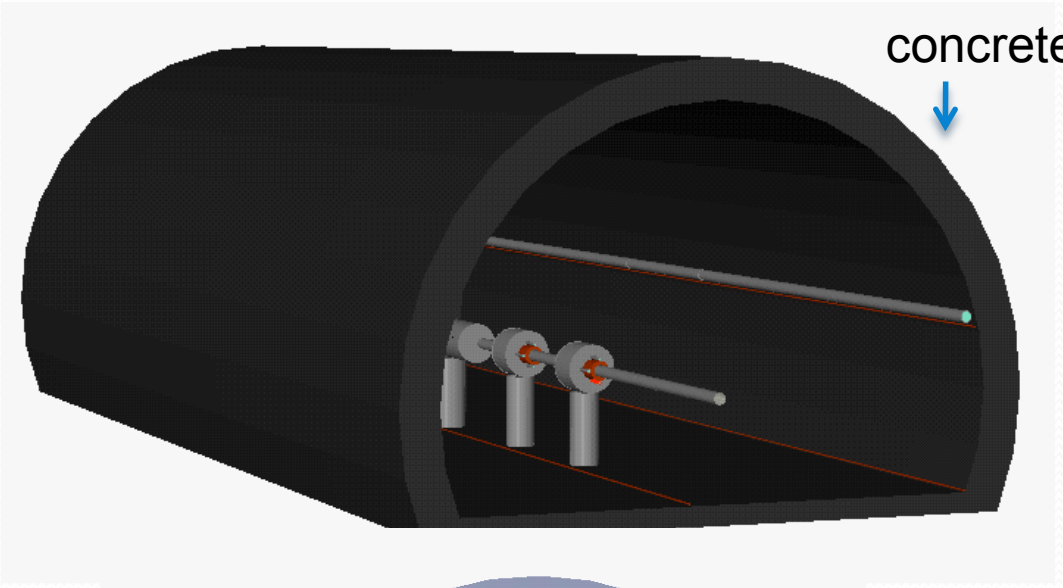


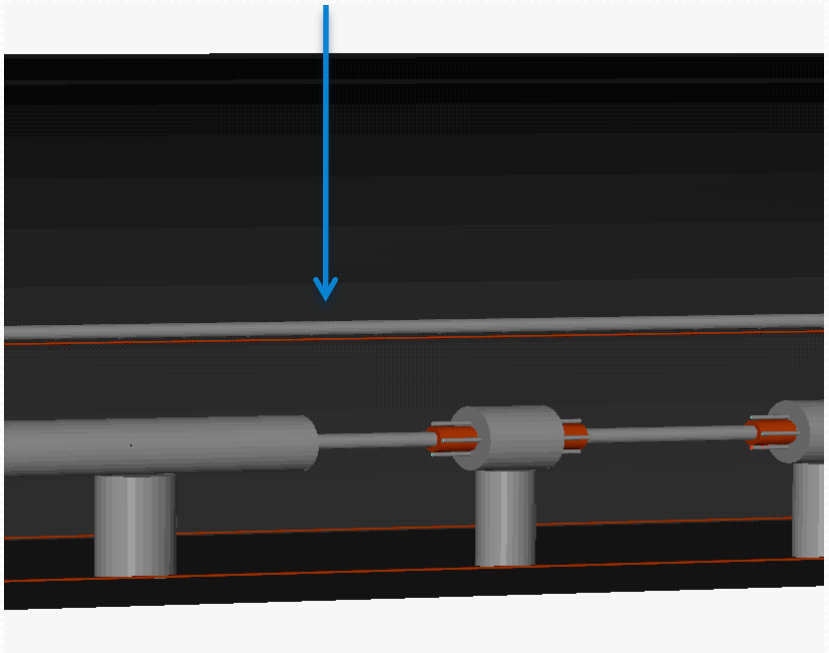

*Circumf.* = 250 m

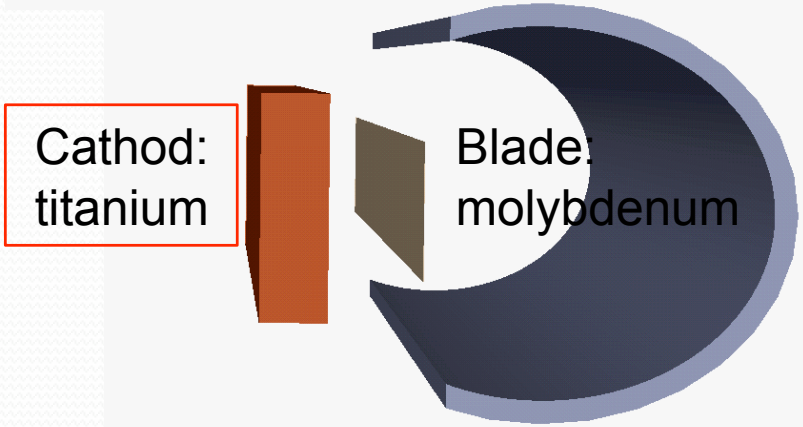
*Tunnel section area* = 18 $m^2$

# Geometry overview

Electrostatic septum, 0.2 mm thick, 1.6 m long

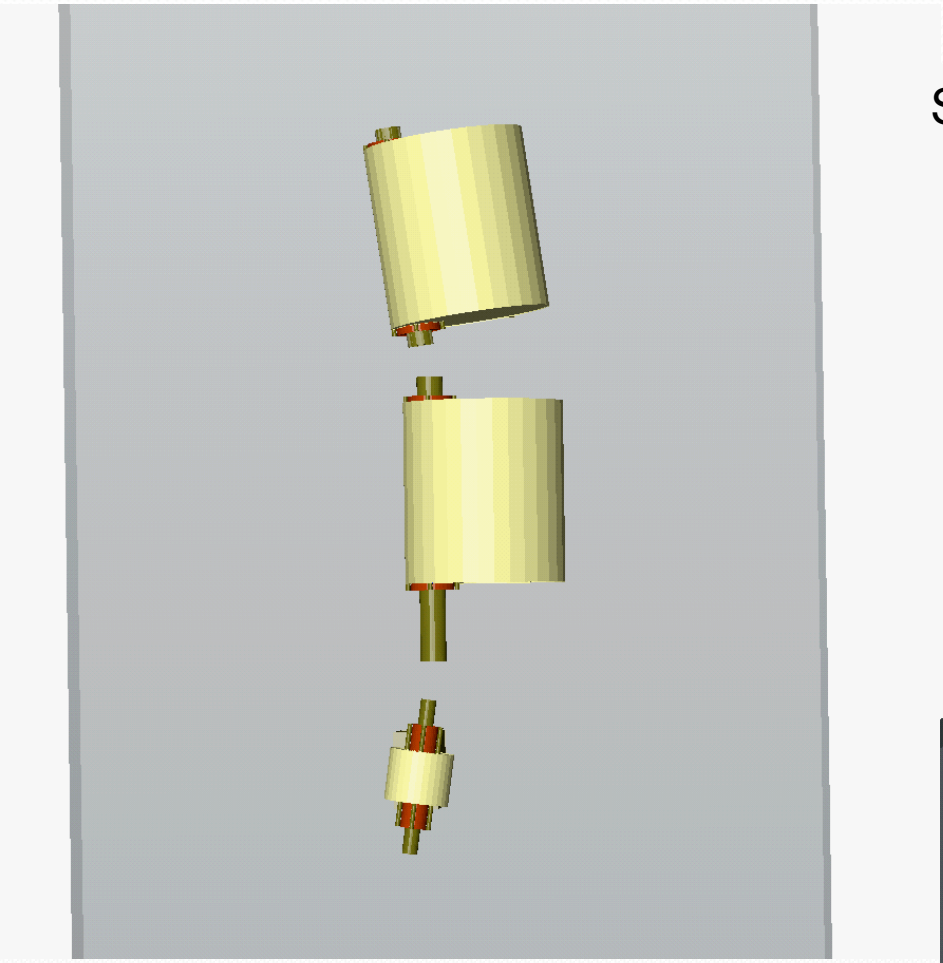


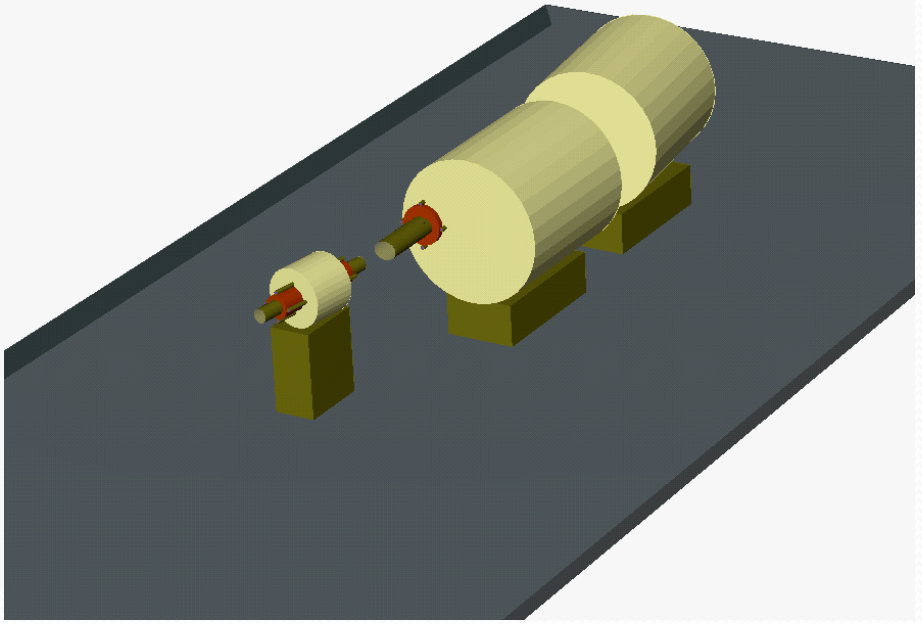



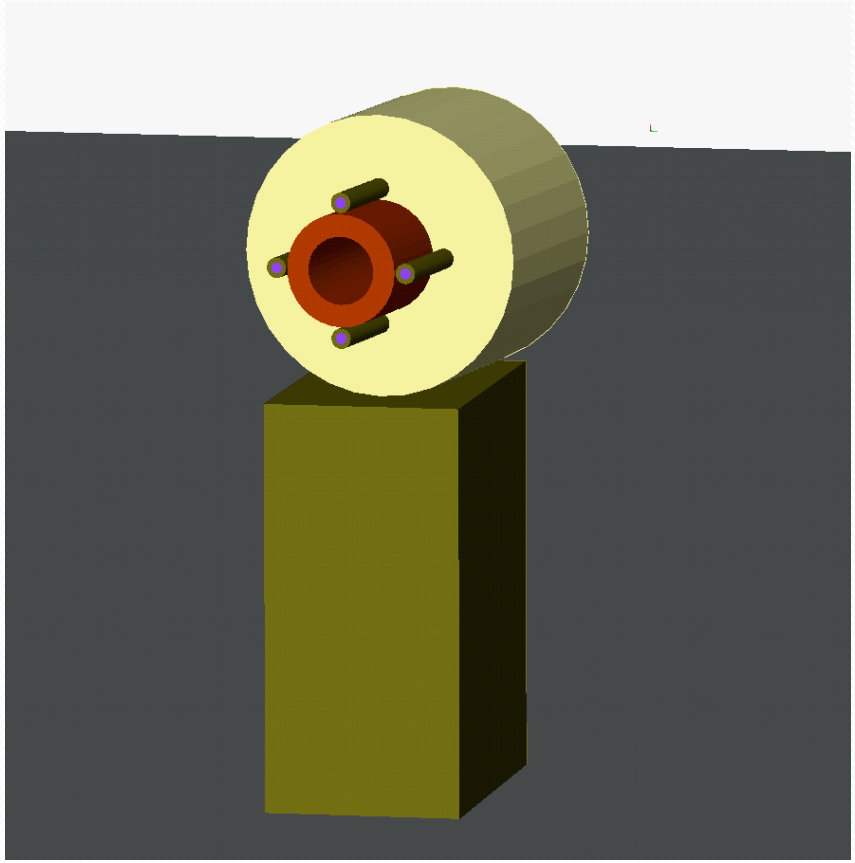

Septum losses: septum + quadrupole + quadrupole

# Arc segment implementation



Stainless steel beam pipe 0.3 mm thick

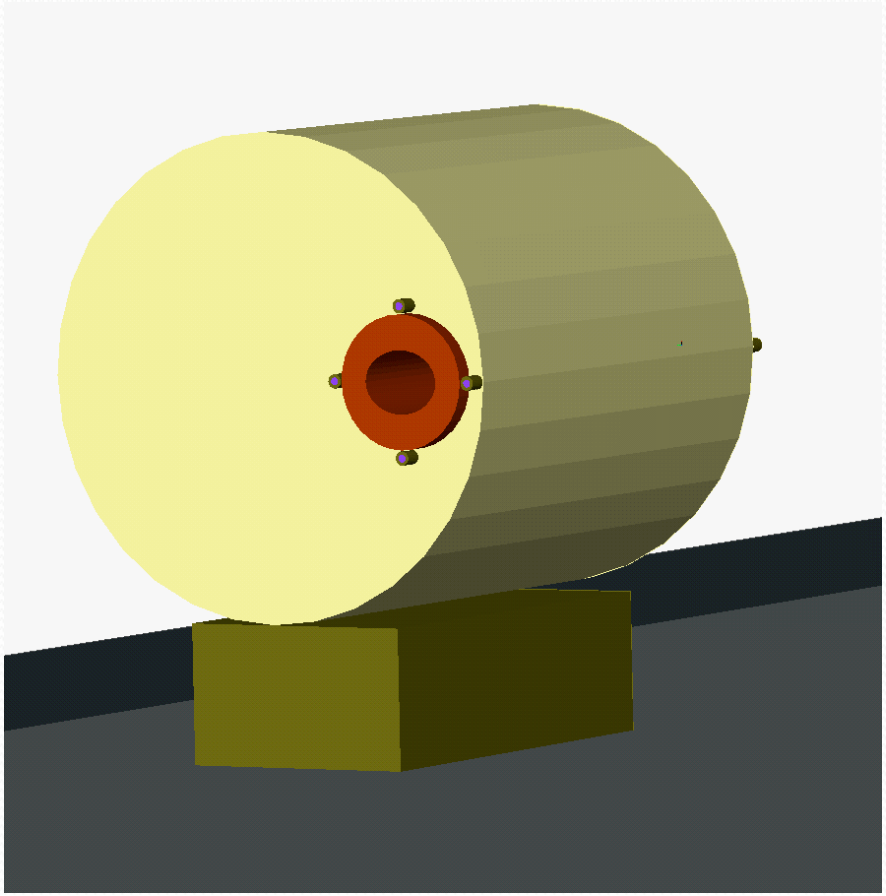




Quadrupole

Return yoke: 0.525 t, iron (98%), silicon (1.5%), manganese (0.2%), aluminum (0.2%) phosphorus (0.05%), carbon (0.001%) and sulfur (0.0005 %).

Coils: 0.146 t, copper



Dipole

Return yoke: 12 t, material: same as for quadrupole.

Coils: 0.72 t, copper

- The dominating reaction channels are:
  - Half-life < 1day:
    - $^{11}C$ (spallation on N and O): $^{14}N(p,\alpha)^{11}C$, $^{14}N(\pi,^{3}H)^{11}C$.
    - $^{13}N$ reactions on nitrogen: (n,2n).
    - $^{14}O$: (p,n) on nitrogen, neutron removal on oxygen.
    - $^{15}O$ (reactions with oxygen, especially neutron removal): (n,2n), ($\pi$,2n).
    - $^{41}Ar$ (low-energy neutron capture on argon).
  - Half-life > 1 day:
    - $^{7}Be$ (spallation by high energy reactions on N (most) and O): reactions on Ar play a minor role.
    - $^{38\text{-}39\text{-}40}Cl$ spallation on argon dominated by neutrons.

# Results

**3 months of continuous operation**

- $^{18}$Ne is the worst case.
- Nuclides that contribute most to total dose are summarized in the table.
- Parameters: F=10000 $m^3$ $h^{-1}$; Volume (RCS)=4320 $m^3$; $T_{decay}$=0.

| Radionuclide | Half -life | Annual dose (μSv) |
|---|---|---|
| N-13 | minutes | 3.12-01 |
| Ar-41 | hours | 1.27-01 |
| C-11 | minutes | 1.17-01 |
| O-14 | seconds | 8.09-03 |
| O-15 | minutes | 8.16-02 |
| Cl-38 | minutes | 8.45-03 |
| Cl-39 | minutes | 1.25-02 |
| Cl-40 | minutes | 1.32-03 |
| Be-7 | months | 3.13-03 |

# Total annual effective dose ($^{18}Ne$)

| F ($m^3\ h^{-1}$) | $T_{decay}$ (s) | Total Annual Effective Dose ($\mu Sv$) |
|---|---|---|
| 5000 | 0 | 0.453 |
| 5000 | 16.2 | 0.447 |
| 10000 | 0 | 0.679 |
| 10000 | 8.1 | 0.676 |

# Airborne activity released

- The RCS air releases in the environment are within CERN constraints.
- The released activity can be further reduced using a slower ventilation factor or bigger ventilation outlets.

# Residual dose during maintenance

- Irradiation cycle: 3 month irradiation followed by 1 hour, 1 day, 1 week waiting times.
- The residual H*(10) rate in $\mu Sv\ h^{-1}$ scored along the tunnel.
- Calculations done for low, medium and high energy intervals.
- The contribution from the low/medium energy interval is negligible with respect to the high energy one.

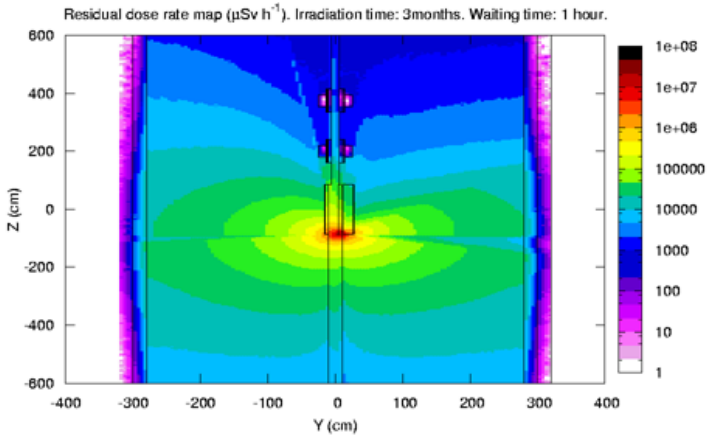
# Radiation areas: classification

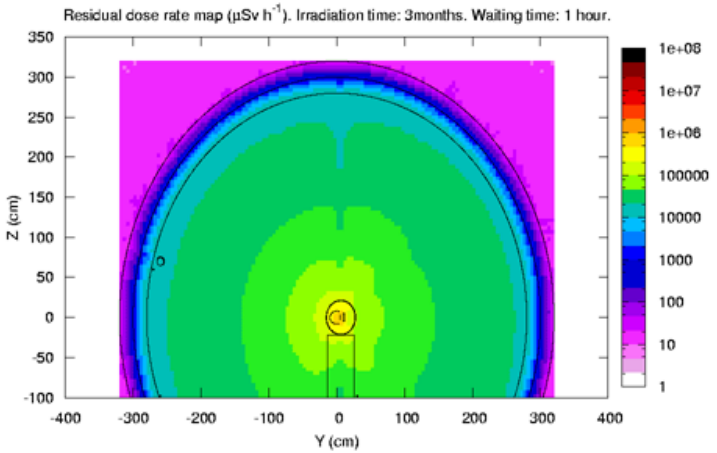
Occupationally exposed workers:
Class A > 6 mSv / 12 months
Class B < 6 mSv / 12 months

| **Area Classification** | **Dose limit** | **Ambient dose equivalent rate** *At permanent work places* | **Ambient dose equivalent rate** *In low occupancy areas* | **Access Personnel categories** |
|---|---|---|---|---|
| Simple Controlled Radiation area | 20 mSv/y | < 10 µSv/h | < 50 µSv/h | Controlled Class A workers Class B with time limit |
| Limited stay area | 20 mSv/y | | < 2 mSv/h | Controlled Class A workers Class B with time limit |
| High radiation area | | | <100 mSv/h | |
| Prohibited area | | | >100 mSv/h | |

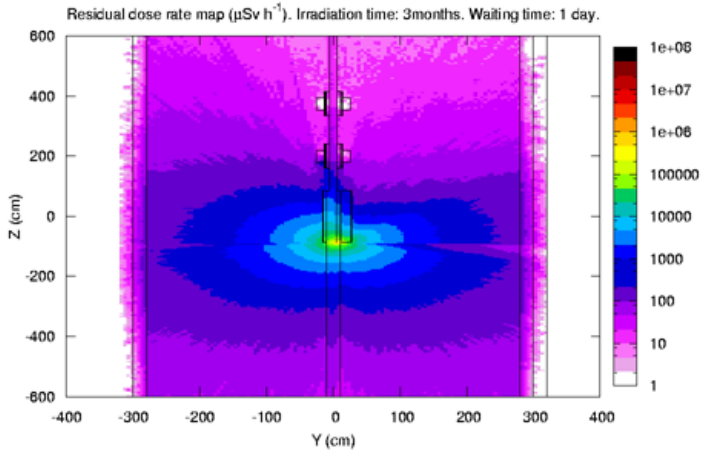
II. Safety code F, classification of areas and personnel

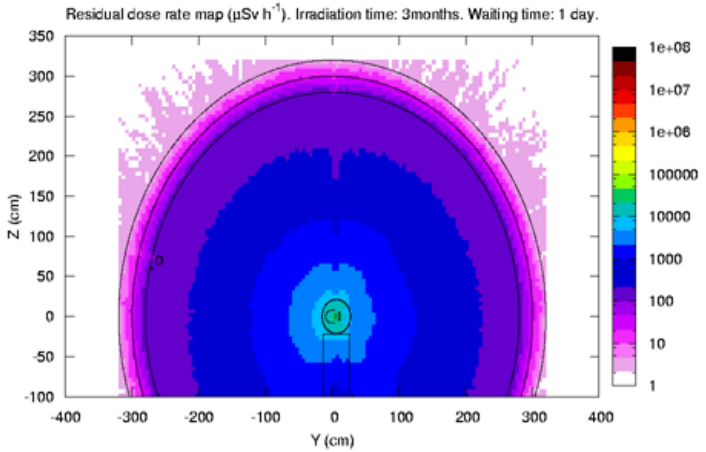
# $^{18}$Ne: injection losses



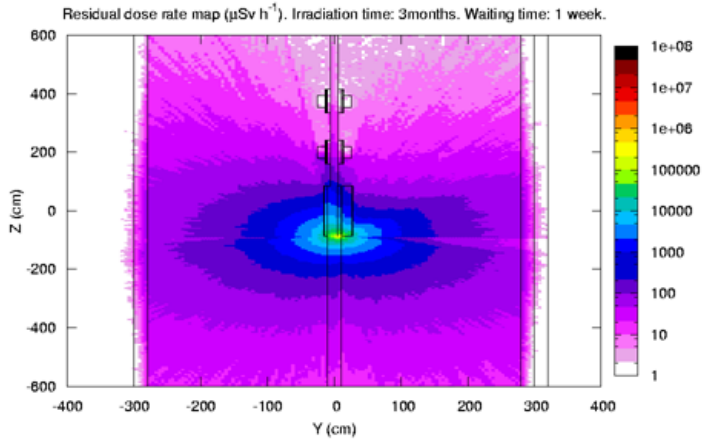



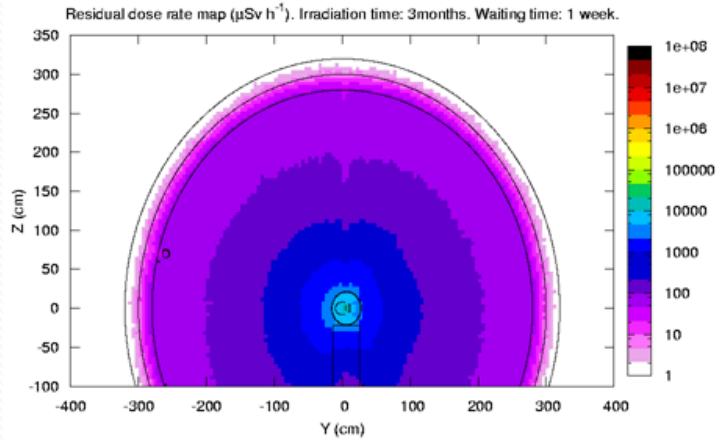

1 HOUR




1 DAY

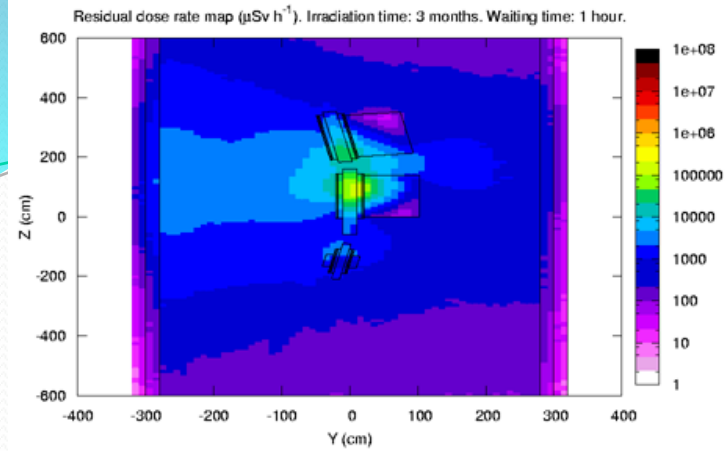


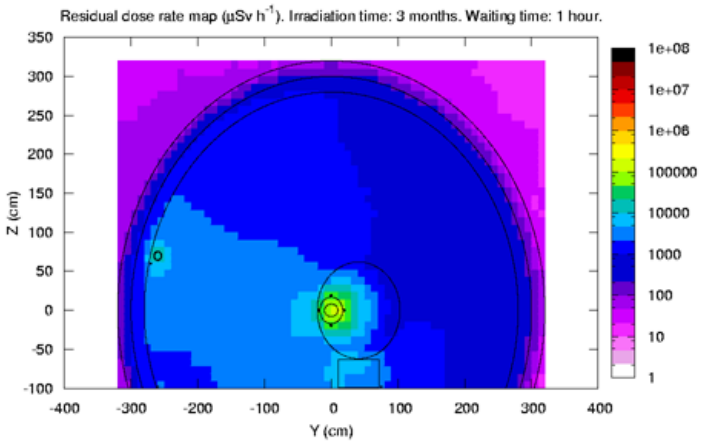




1 WEEK

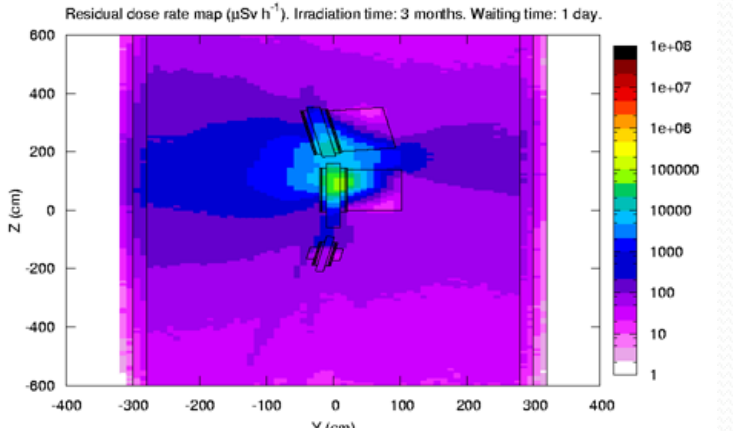
Limited stay area after 1 week

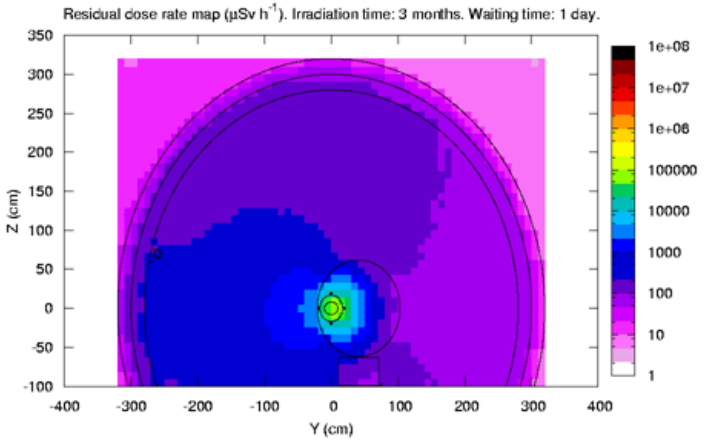
# $^{18}$Ne: decay losses 1650 MeV/u



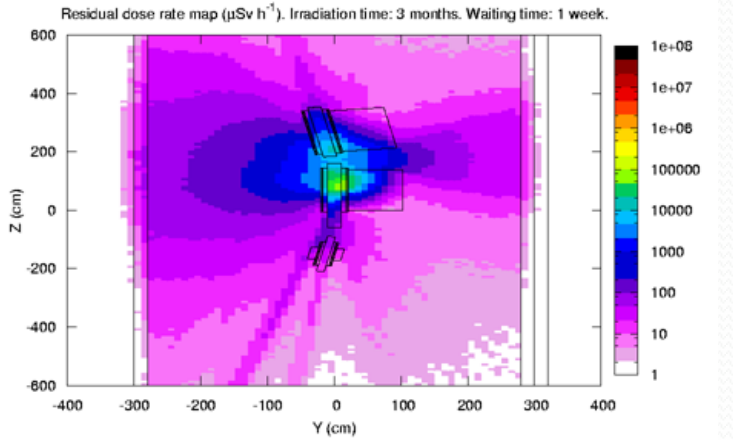



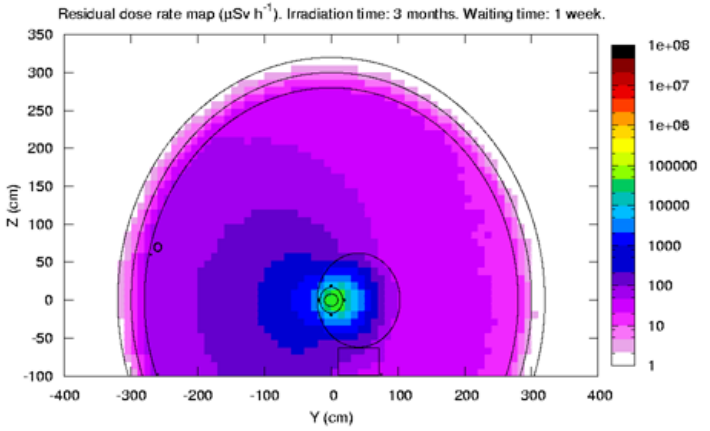

1 HOUR




1 DAY

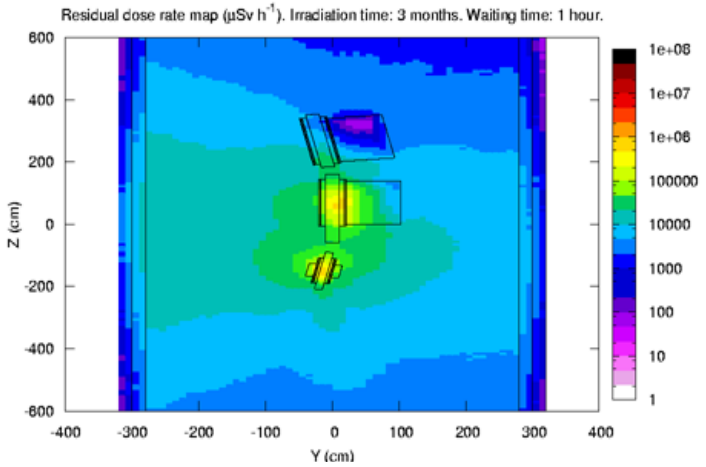


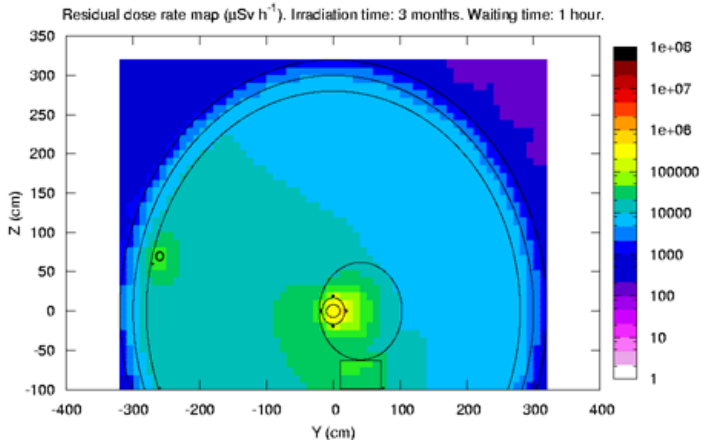




1 WEEK

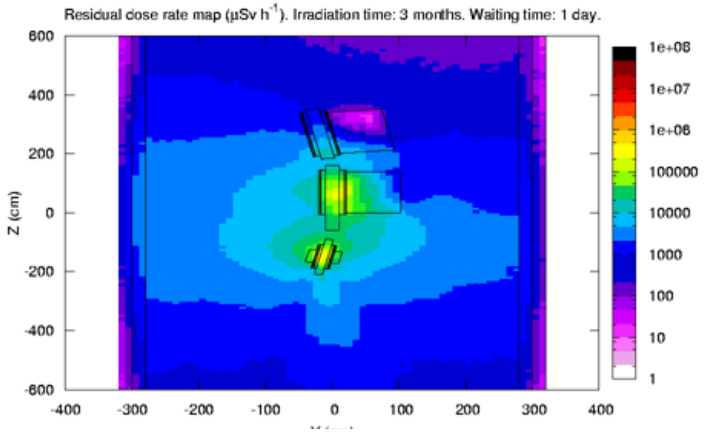
Limited stay area after 1 week

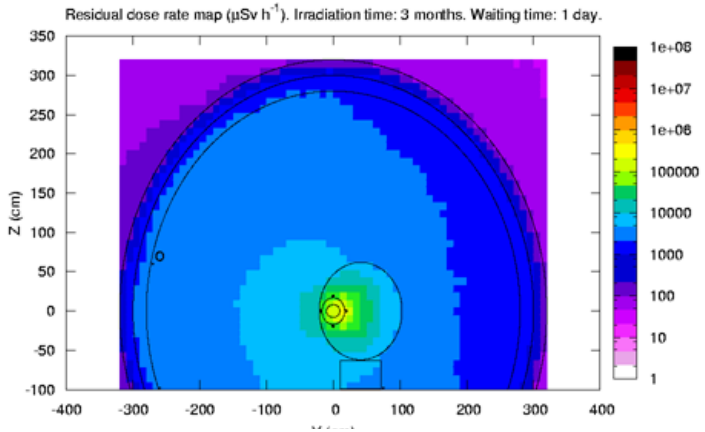
# $^{18}$Ne: RF-acceleration losses 1650 MeV/u



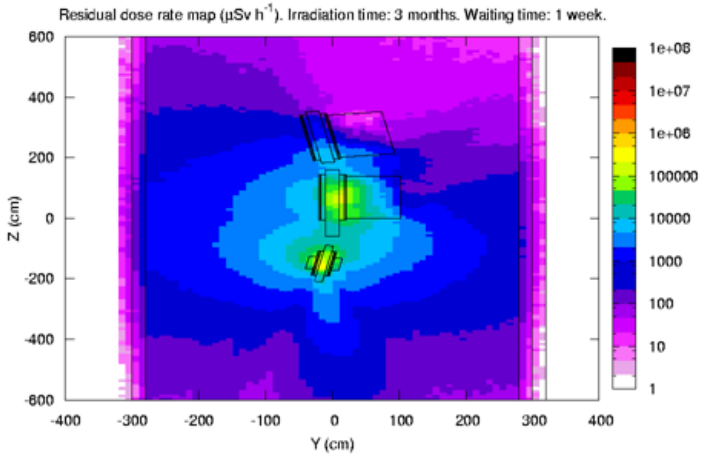



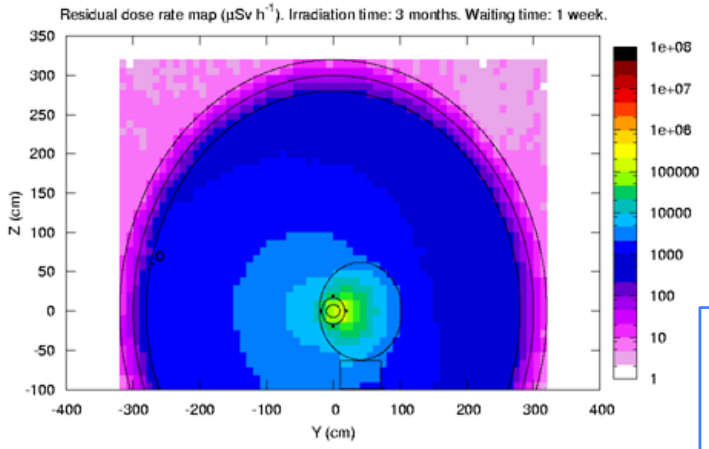

1 HOUR




1 DAY




1 WEEK

Limited stay area after more than 1 week

# Dominant residual gamma emitters

- $^{60}$Co: 5.27 years
- $^{22}$Na: 2.603 years
- $^{56}$Co:  77.26 days
- $^{57}$Co: 271.79 days
- $^{58}$Co: 70.86 days
- $^{51}$Cr: 27.7 days
- $^{54}$Mn: 312.2 days
- $^{56}$Mn: 2.58 hours

# Conclusions

- Released airborne activity is within Swiss constraints.
- Area classification according to CERN: limited stay controlled area, accessible after 1 week or more depending on the position.

- TO BE DONE NEXT:
  - water activation