First radiation protection considerations for a muon collider target area

C. Ahdida, H. Vincke, P. Vojtyla, M. Widorski

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Overview

- General principles and guidelines of Radiation Protection
- General RP considerations for a muon collider target complex
  1. Prompt and residual radiation
  2. Air and He activation
  3. Water and soil activation
  4. Radioactive waste production
- Summary

General Principles of Radiation Protection

ICRP recommends the international guidelines, which are transcribed into law on European and national level

1. **Justification**
   Any exposure of persons to ionizing radiation has to be justified

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2. **Limitation**
   The personal doses have to be kept below the legal limits

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3. **Optimization**
   The personal doses and collective doses have to be kept as low as reasonably achievable (ALARA)

Limitation – Example of CERN Safety Code F

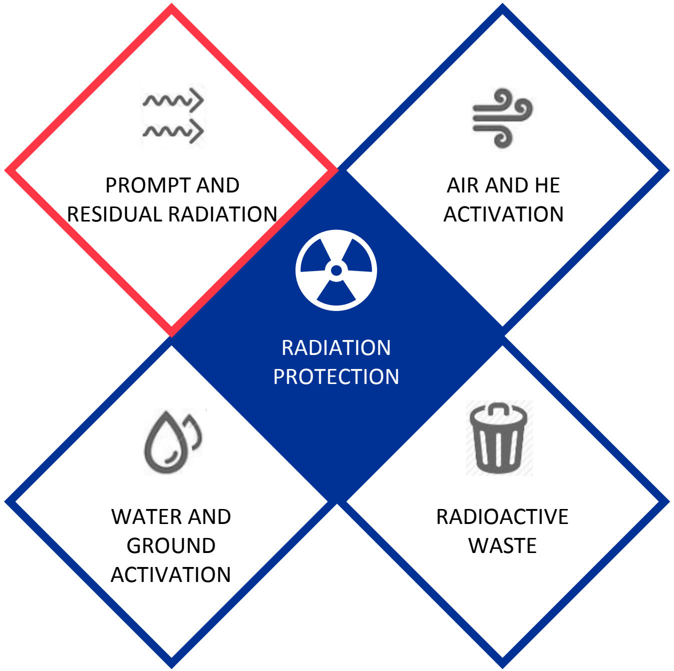
	Yearly limit
Occupationally exposed persons (Radiation Workers) *3.2.1* The effective dose received in any consecutive 12-month period by any occupationally exposed person must not exceed 20 mSv. *3.4.1* All occupationally exposed persons are classified in one of two categories: a) Category A: persons who may be exposed in the exercise of their profession to more than 3/10 of the limit in terms of effective dose in 12 consecutive months. b) Category B: persons who may be exposed in the exercise of their profession to less than 3/10 of the limit in terms of effective dose in 12 consecutive months.	A: **20 mSv/12 months (*)** B: **6 mSv/12 months (*)** (*) Age 16-18: 6 mSv/12 months, Pregnant women: 1 mSv during pregnancy
Not occupationally exposed persons *3.2.3* The effective dose received in any consecutive 12-month period by persons not occupationally exposed must not exceed 1 mSv.	**1 mSv/12 months**
Environment (Public) *4.2.1* The effective dose resulting from CERN's activities received by any person living or working outside the site boundaries must not exceed 0.3 mSv per year. This limit includes both external and internal exposure, the latter resulting from the intake of radioactive releases.	**0.3 mSv/12 months**

→ **Optimisation** can be considered as respected if the practice never gives rise to an annual dose above **10 µSv** for members of the public

https://edms.cern.ch/ui/file/335729/LAST_RELEASED/F_E.PDF

100 rem = 1Sv

General RP considerations



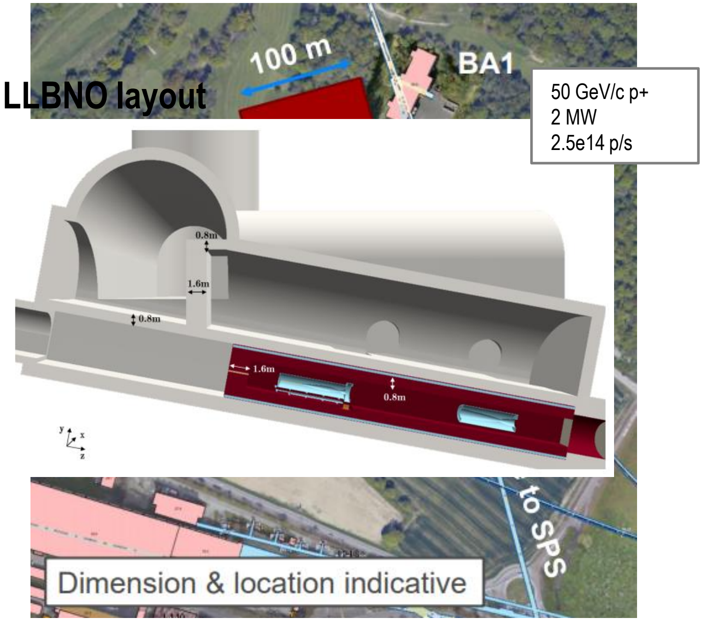
Prompt and residual radiation

- The **optimization** of the prompt and residual radiation must be taken into account for **commissioning, normal beam operation, maintenance and accidents**
- To lower the prompt and residual radiation, **adequate shielding** needs to be installed
- The **activation properties** of the materials used in the facility must be considered during the design process, as they may have a direct impact on later handling and waste disposal. For this the ActiWiz material catalogue could be consulted
- **Only absolutely necessary equipment** should be installed in areas of high radiation levels. The higher the activation, the more **reliable** should equipment be
- Depending on residual dose levels and tasks, manual interventions should partially or completely be replaced by **remote maintenance/ repair**. Any component should be optimized to lower maintenance time and repair needs

Prompt and residual radiation

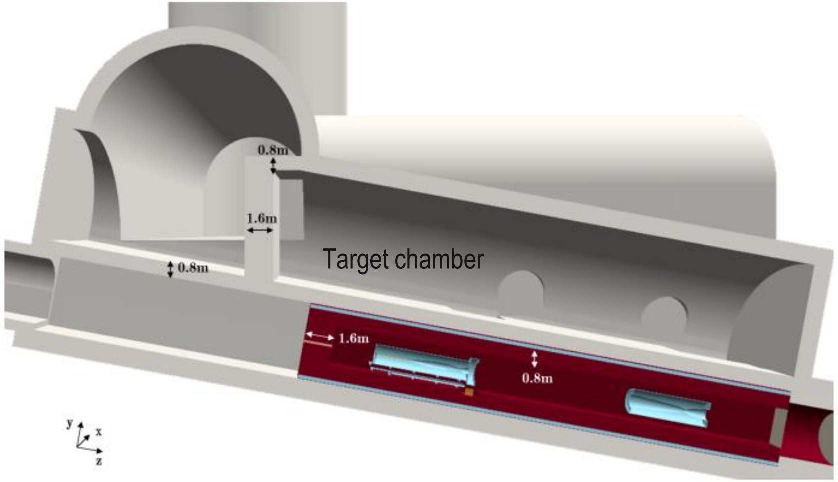
- Fully underground solution of around 40 m depth (e.g. “TT10-like”) reduces RP concerns due to prompt radiation
- Depth of around 40 m for a O(4) MW facility is sufficient for the dose above-ground, but ground water activation to be checked (depth for 2 MW LLBNO was of O(80-100) m)
- Considerable shielding for MW facility is nevertheless required to reduce the prompt radiation and thus the resulting activation levels of the surrounding infrastructure and molasse
- Remote handling is required
- A morgue room could be foreseen for allowing cooling of hot equipment
- Streaming through shafts connected to the target area should be sufficiently reduced

“TT-10-like” option

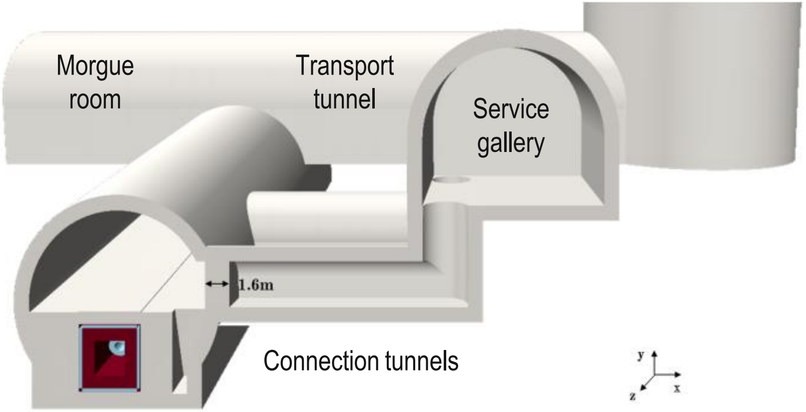


LLBNO design

Side view



Cross-sectional view

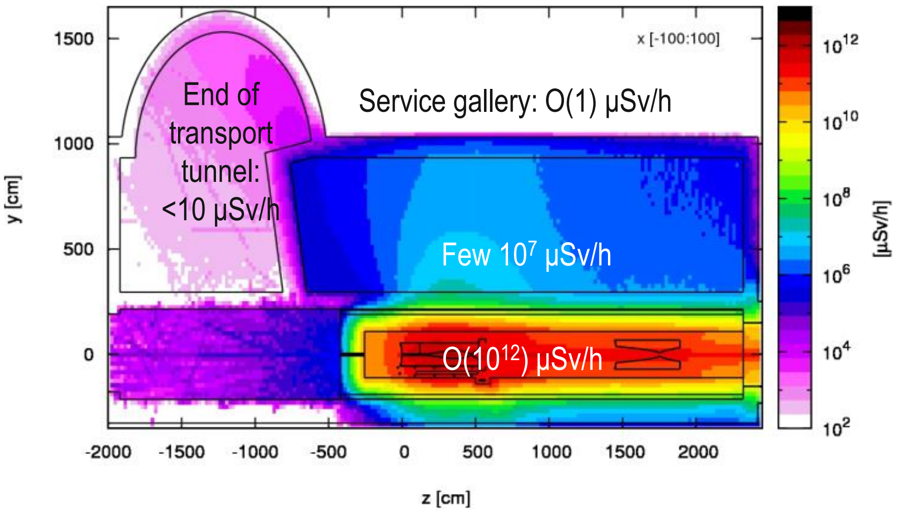


Iron

Concrete

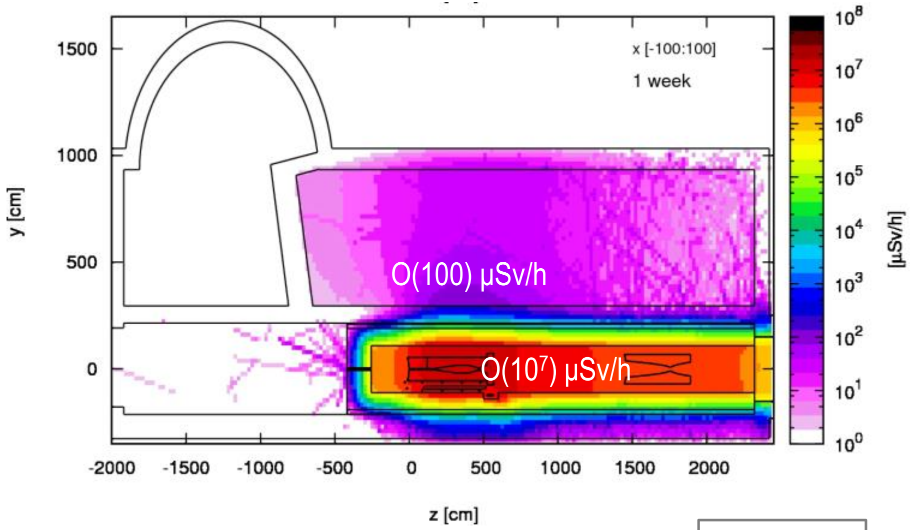
LLBNO prompt and residual dose rates

Prompt dose rates



Above-ground: < 0.05 µSv/h

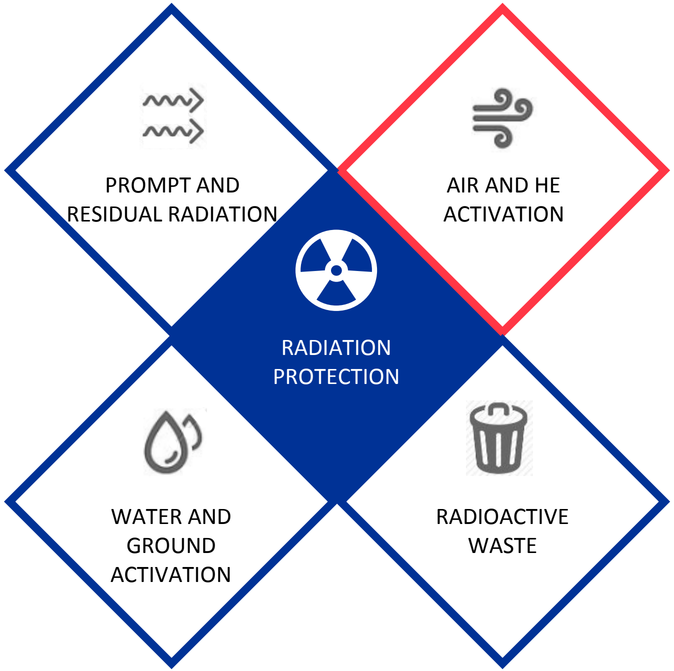
Residual dose rates, 1 week cooling



Target at contact: up to 10^8 µSv/h

50 GeV/c p+
2 MW
2.5e14 p/s

General RP considerations



Air and helium activation

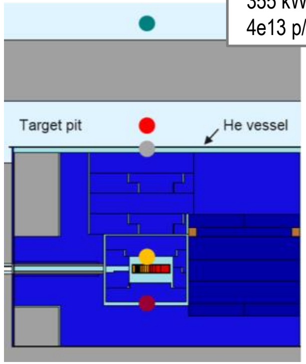
- **Air volumes** should be **minimized** in areas of high levels of prompt radiation or even better be **replaced** by a **helium** or **vacuum** environment
- Air volumes in which considerable air activation is expected should be separated from adjacent areas and the outside. Therefore, both **static** (e.g. sealing of air volumes) and **dynamic** (e.g. leak extraction) air **confinement** should be employed
- A ventilation system should guarantee a **pressure cascade** from **low to high contaminated areas**
- The air extraction system shall be equipped with high-efficiency particle and aerosol (HEPA) **filters** and an **air monitoring station**

Air and He activation

- BDF as an example for a optimized design with a minimization of air volumes by a He vessel around the target and proximity shielding
- A requirement of a max. air contamination level of 0.1% was set
- For a O(4) MW facility a He vessel would definitely be required (initial guess > 100 kW)
- At BDF also a dynamic confinement was employed as well as HEPA filters to effectively reduce radionuclides attached to aerosols (Be-7, Na-22/24, P-32/33 and S-35)
- Environmental impact from releases of activated air/He to be evaluated
- Effective dose to members of the public to be <10 µSv/year from all CERN facilities and all sources (stray radiation, air/He releases, water activation, etc.)
- Uncertainty connected to H-3 outgassing from shielding elements (eventually also target)

BDF

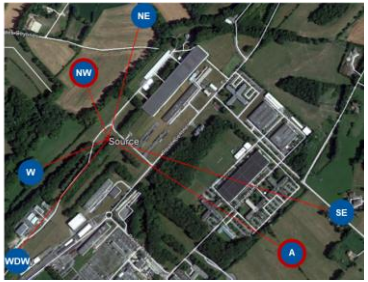
400 GeV/c p+
355 kW
4e13 p/s



Volume	Activity [Bq] Air	Activity [Bq] He	Multiple of CA Air	Multiple of CA He
Middle He	7.8×10^5	4.1×10^7	1.3×10^3	8.7×10^{-4}
Inner He	5.6×10^7	2.8×10^9	7.5×10^5	4.2×10^{-1}
External He	1.5×10^2	9.0×10^3	2.0×10^{-2}	1.5×10^{-8}
Lower air	1.7×10^7	–	7.0×10^{-1}	–
Upper air	8.3×10^4	–	6.7×10^{-3}	–

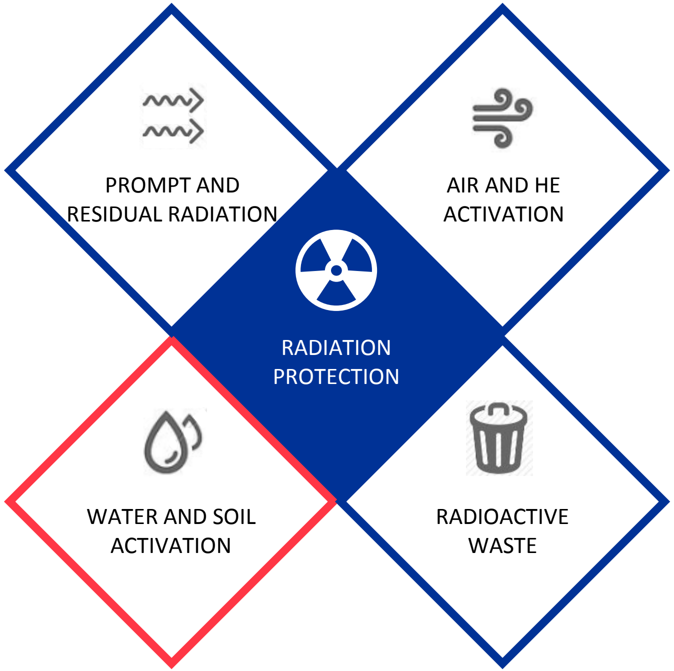
Main contribution from 0.1% air contamination in inner He region

Identification of reference groups around BDF to evaluate dose to public from air / He releases
→ highest value of 10 nSv per year



[1] Person working 40h/w, 50w/y with standard breathing rate (1.2 m^3/h) in activated air with CA = 1 receives 20 mSv

General RP considerations



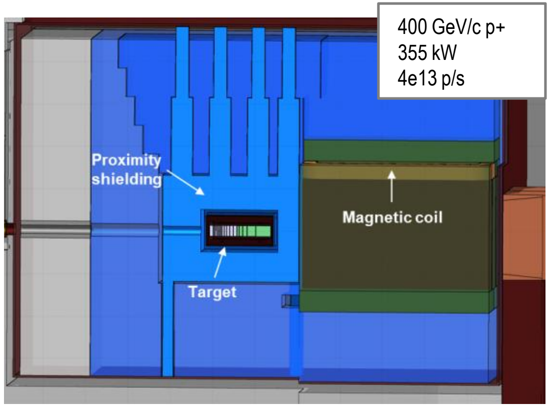
Water and soil activation

- **Water cooling circuits** for highly radioactive elements like the target and the dump should be **closed** and **separated** from others
- Water **sumps** should be **avoided** in **highly activated areas**
- **Activation** and/or **contamination** of **ground water** and **earth** should be avoided (e.g. by adequate shielding, dedicated sumps)
- The facility should not be built in a “wet” environment. A **hydrological study** of the envisaged site should therefore be performed
- **Soil samples** should be taken and analysed for their chemical and radiological composition

Water activation

- Required depth for final O(4) MW facility to be checked for ground water activation (depth for 2 MW LLBNO was of O(80-100) m)
- Ideally the placement of the most activated elements to be in deep impermeable molasse that is not in contact with shallower aquifers in moraine above and not suitable for drinking water exploitation
- Environmental impact expected from molasses activation can be investigated with activation studies in combination with a hydrogeological study
- For ground-water protection also geo-membranes can be employed
- Activation of cooling water in the facility also to be taken into account like it was done for BDF
- A large uncertainty for the cooling water activation comes again from H-3 out-diffusion
- The use of an evaporator for eliminating activated water to be investigated (dosimetric impact)

BDF



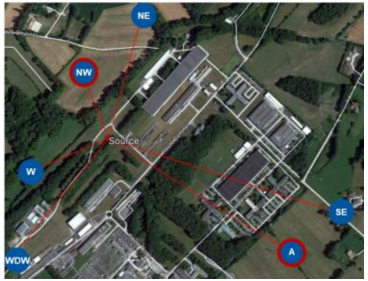
74 GBq from direct H-3 production (5 yrs)

18 TBq H-3 concentration in the target (5 yrs)

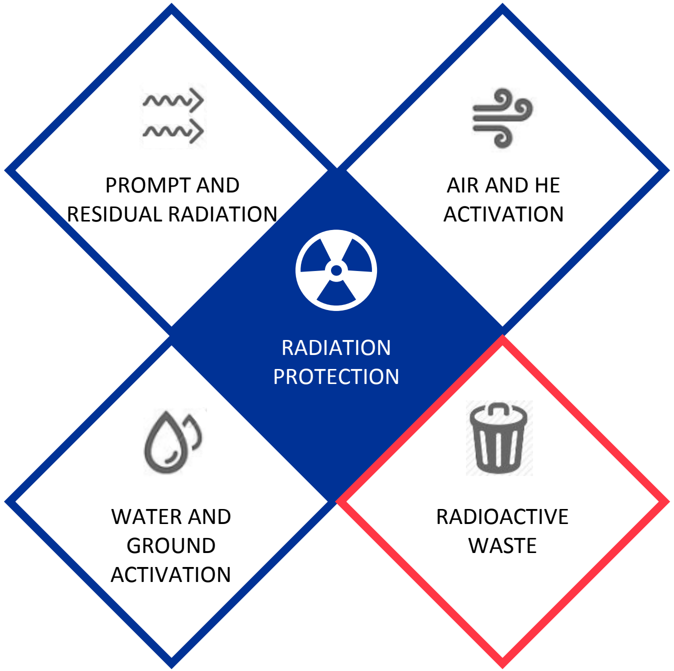
180 GBq assuming 3% out-diffusion from the target

3 demineralized water cooling circuits in BDF

Environmental impact from evaporation of cooling water (H-3) with 280 GBq H-3 was assessed to be of about 50 nSv/y



General RP considerations



Radioactive waste

- The design must consider **minimization, decommissioning** and **dismantling** of radioactive waste

Radioactive waste production

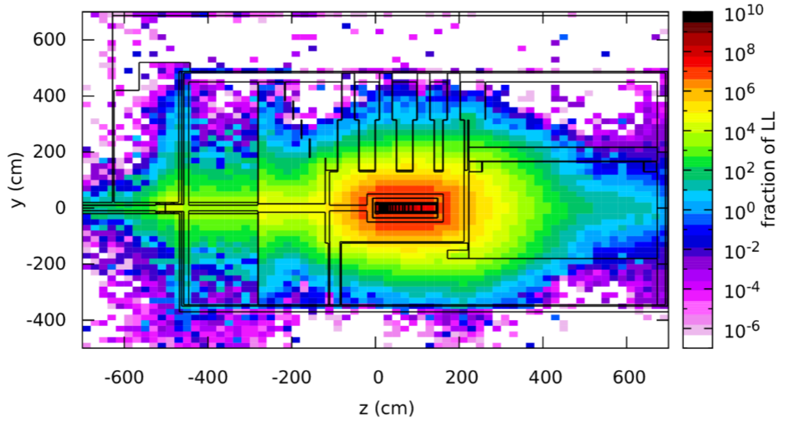
- The **minimisation** of radioactive waste is to be taken into account in the shielding design e.g. by having a **modular shielding** such that **activated parts** can easily be **separated** from **non-radioactive parts**
- To distinguish areas of radioactive waste from conventional ones the Swiss clearance limits (LL) were used
- The following sum rule was applied for material containing a mixture of radionuclides

$$\sum_{i=1}^{n} \frac{a_i}{LL_i} < 1$$

a_i - specific activity (Bq/kg) or total activity (Bq) of the i^{th} radionuclide
LL_i - respective Swiss clearance limit for the radionuclide i
n - number of radionuclides present

BDF

1 year of cooling



For BDF, the fixed concrete structure of the building stays non-radioactive, which was envisaged in order to keep the flexibility for future installations

Summary

- In past studies we have seen that the radiation protection considerations strongly determine the design of high power facilities
- When aiming for a target facility of O(4) MW several RP aspects should be studied beforehand such as:
  - The required shielding and other infrastructure (e.g. morgue room) as well as streaming of radiation through shafts (e.g. avoided by chicanes)
  - The required depth of the facility for avoiding ground water activation and a hydrogeological study
  - A He vessel around the most critical region (target) to avoid air activation
  - The possibility for minimizing the radioactive waste production
- Uncertainties related to H-3 out-diffusion may impact air/He/water activation

International
MUON Collider
Collaboration

CERN

Thank you
for your attention!