Radiation Protection during design, operation and dismantling of target areas

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based on material from RP group

Proton Target Areas at CERN

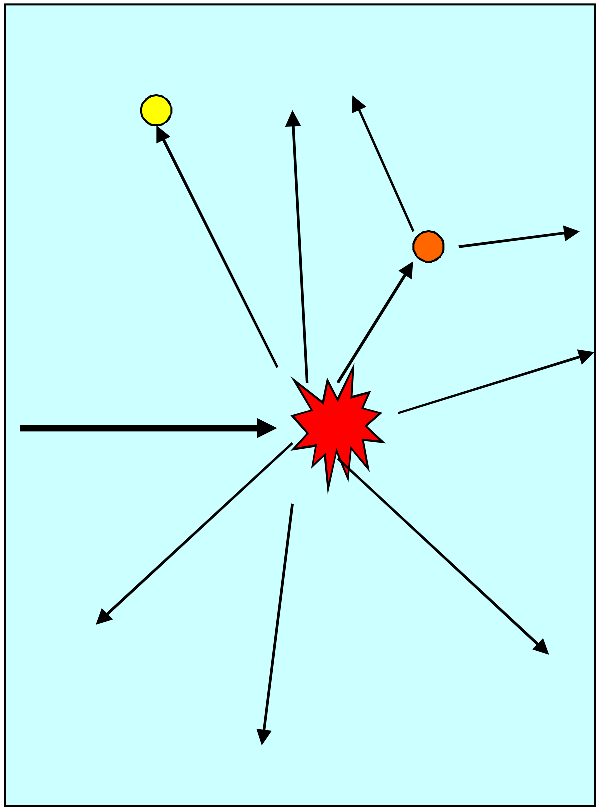
AD	26 GeV/c	0.24 kW
N-TOF	20 GeV/c	1.25 kW
ISOLDE	1.4 GeV	3 kW
North	400 GeV/c	10's of kW
CNGS	400 GeV/c	440 kW

Radiation Protection Items

- Ionisation and radiolysis
  - Chemically Aggressive atmosphere (NO_x, O_3)
- Activated air (spallation, activation)
  - Release to the environment
- Activation of ground and potentially ground water
  - Environmental concern (^{3}H, ^{22}Na)
- Material activation
  - High ambient dose rates from activated material
  - Future radioactive waste

Air Ionization and Activation

- Energetic secondary particles emerge from target
- Traverse air, ionize and activate
- $\Sigma A \sim \lambda$ (pathlength in air)
- Estimate activation by heuristic formulae or Monte-Carlo simulation
- Mainly short-lived beta-plus emitters ^{11}C, ^{13}N, ^{15}O, ^{41}Ar



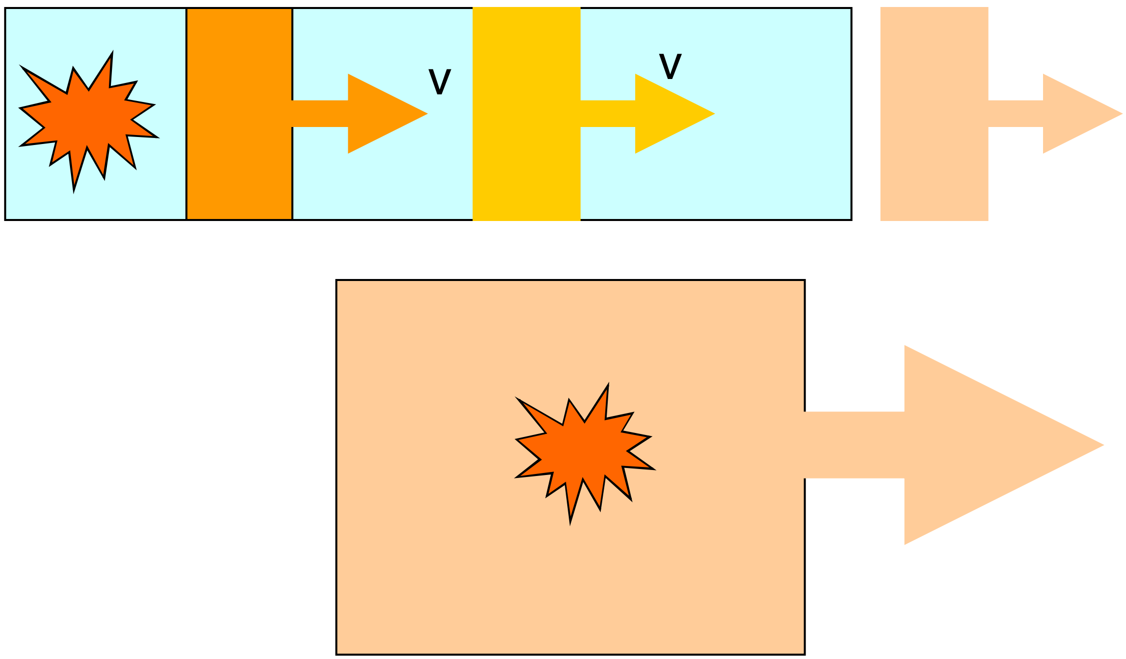
Purpose of “Nuclear” Ventilation

- Create dynamic depression in the most radioactive area – protect other areas from leaking of activation/ contamination
- Direct airflow to release point
  - Allow release at a suitable point (e.g. at height)
  - Permit aerosol filtering at unique point
  - Permit monitoring at unique release point

- Plus the usual purposes of ventilation, such as cooling, removal of noxious agents …

Transport and Release of Air

- Two simplifying cases:
  - Laminar flow of air volume at speed *v* (e.g. in tunnel)
  - Complete mixing of air in target volume, average dwell time τ



Under these assumptions, activation release rate (Bq/s) can be estimated from ventilation speed

ISOLDE 2007

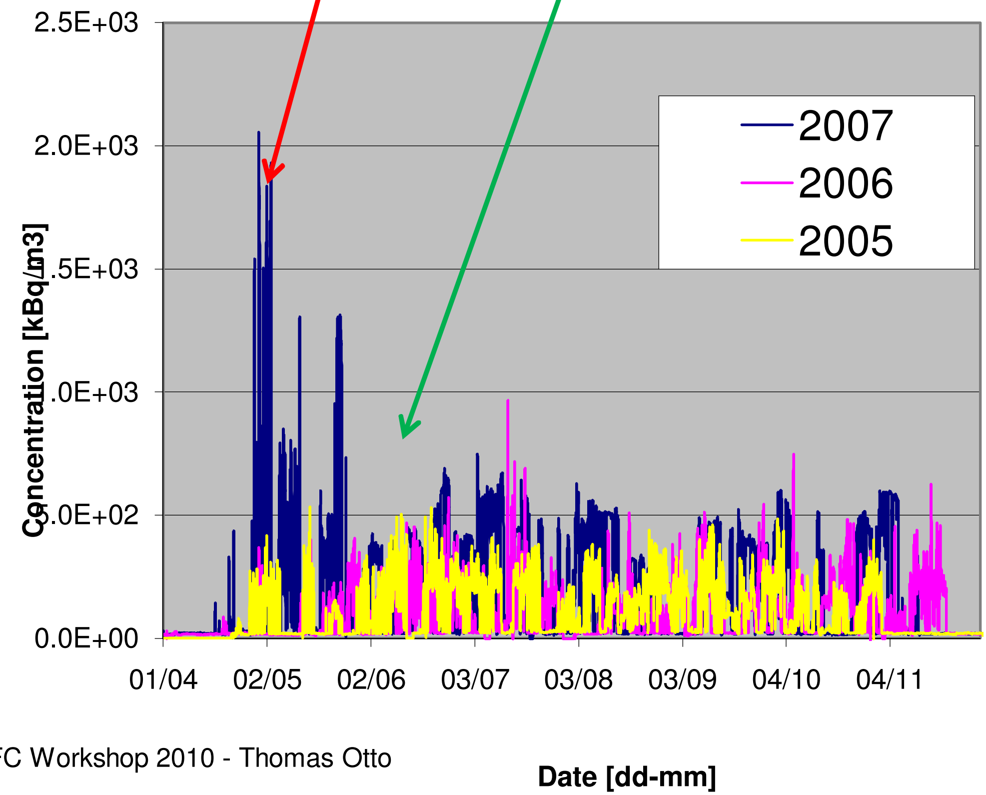
The simplifying assumptions do not always work as advertised.

Small changes in air flow may have a big effect.

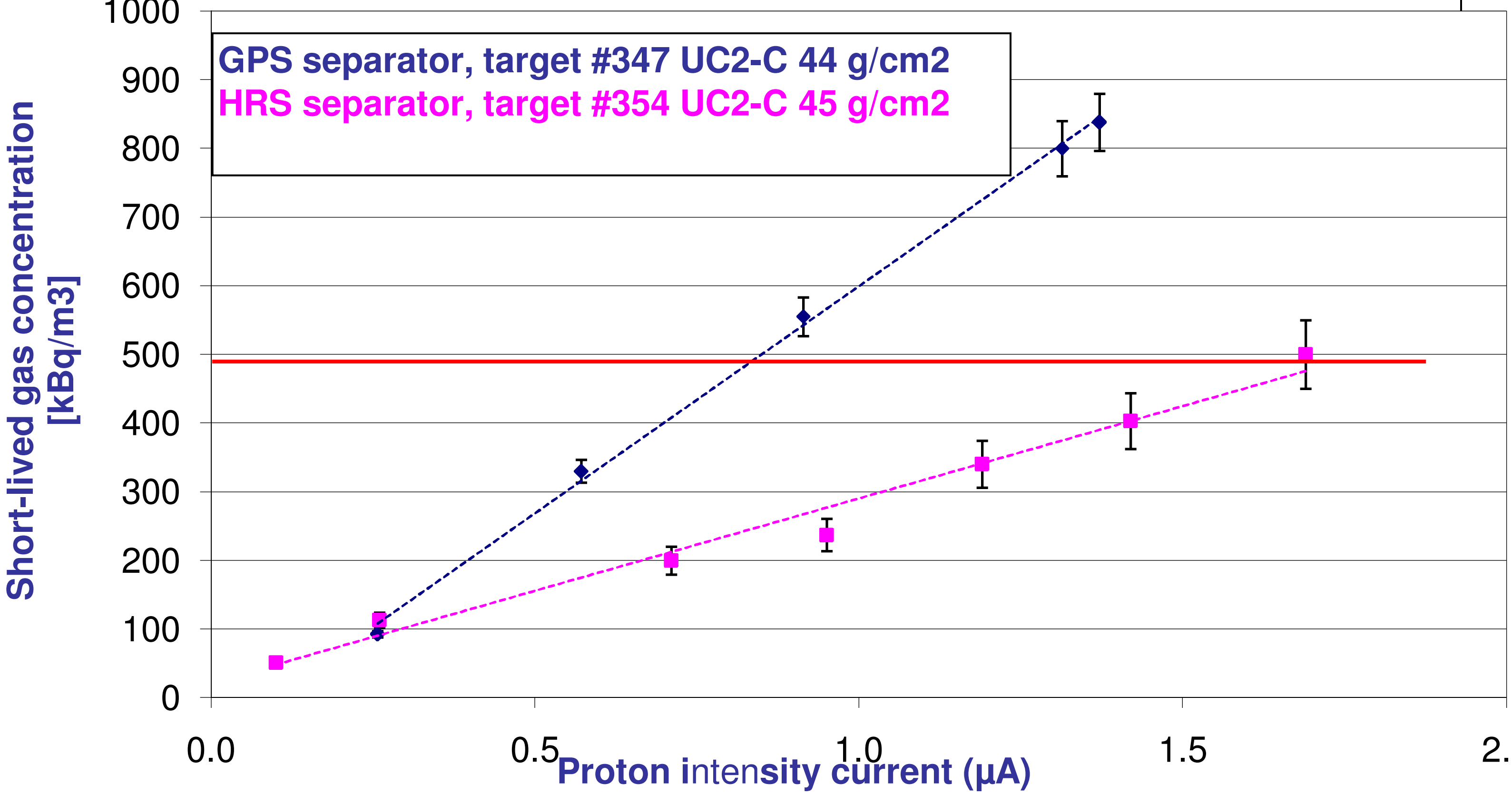
It took man-months of work at ISOLDE to re-establish release figures similar to those achieved before 2007

2007: 3-times higher activity concentration at stack **for equal proton beam** current

“solved” by intensity limitation



Release vs. current

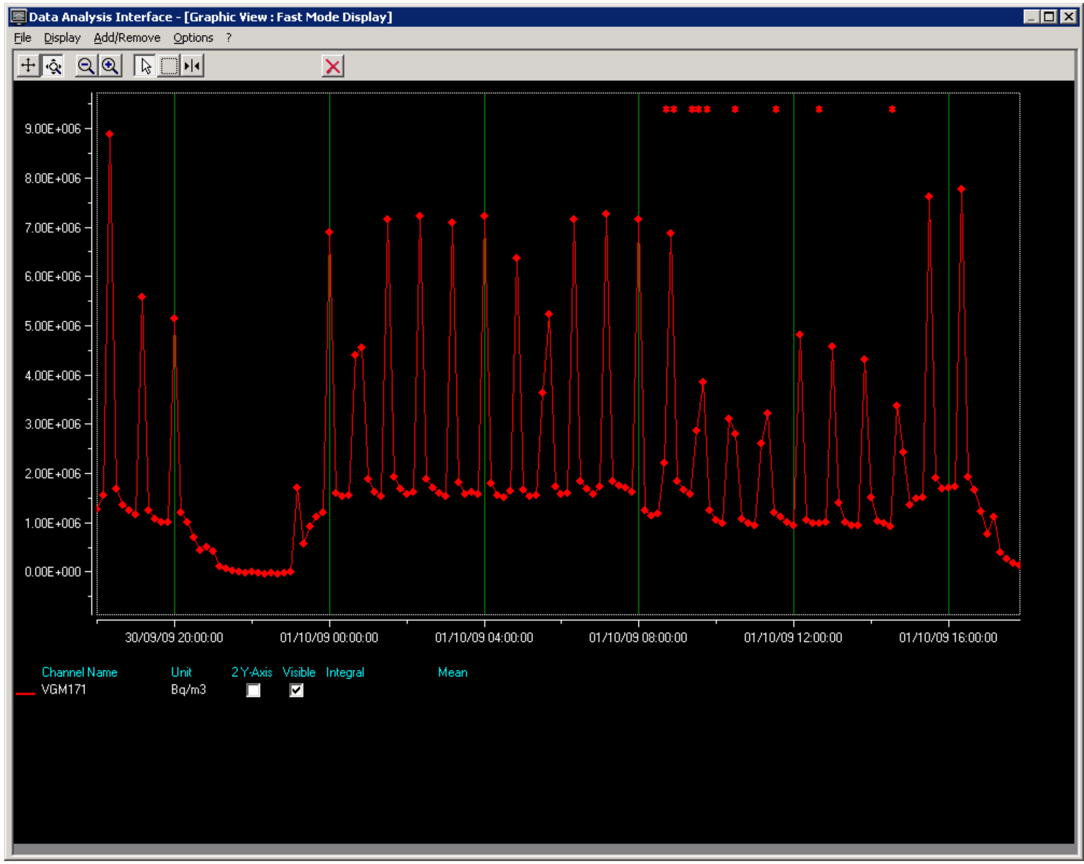


Activity production functions as expected !

n-TOF 2009

Integrated release higher than expected

- lack of tightness in target area requires higher extraction rate
- Spikes ??
  From degassing system of cooling water: ^{15}O
- Solved by additional delay / decay tank

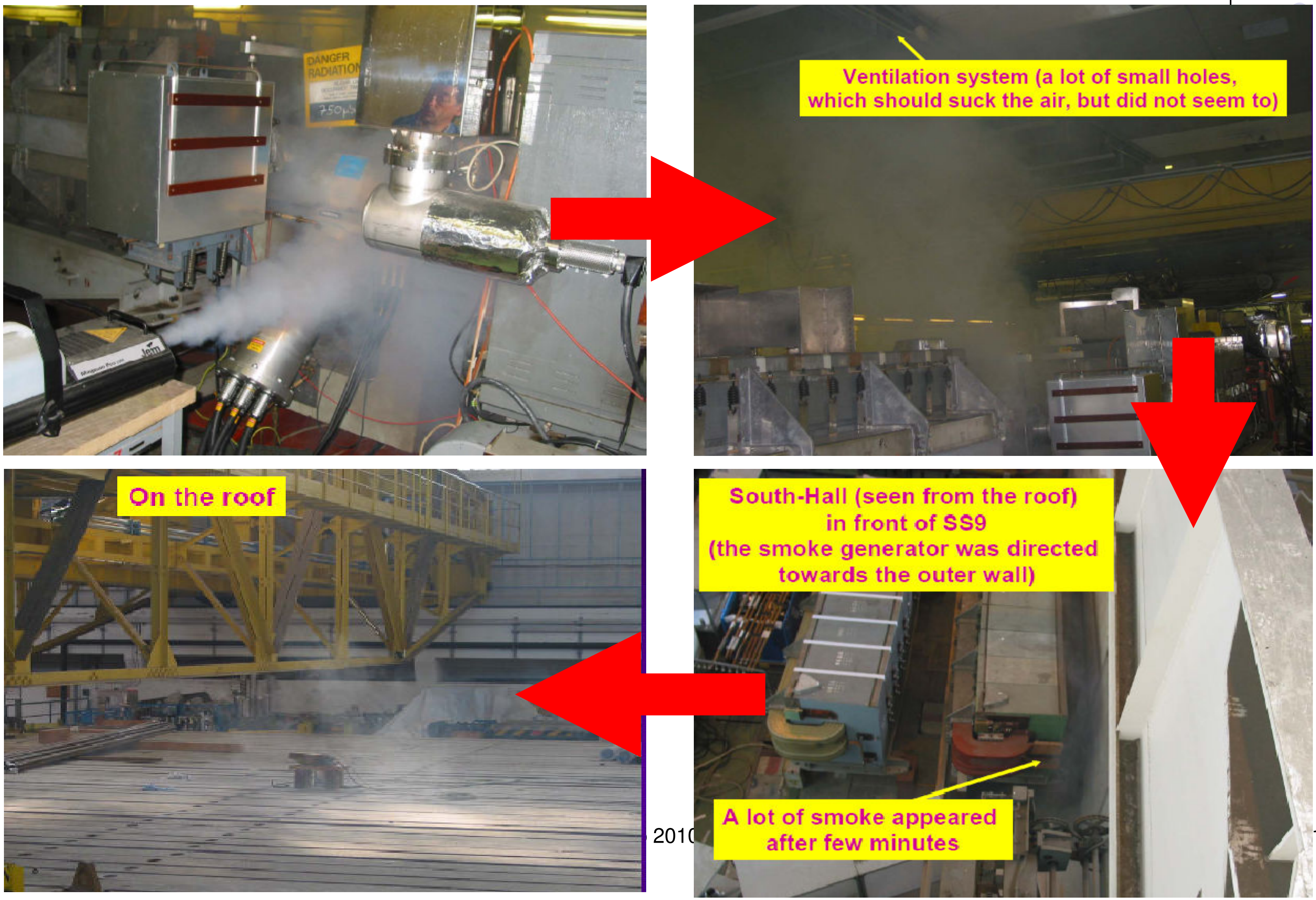


Due to current interest:
No directed extraction - PS

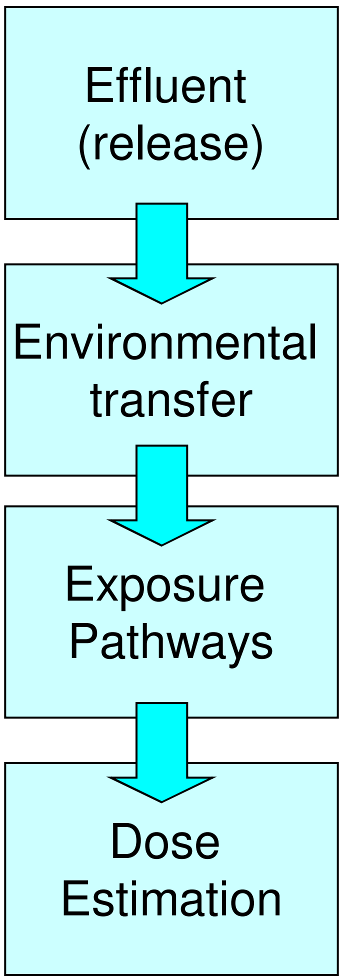
- PS volume ≈ 24 000 m^3
- Ventilation injects 40 000 m^3/h
- 1.7 exchanges / hour
- *p*(tunnel) higher than *p*(environment)

- Smoke tests revealed:
  - Uncontrolled release
  - One reason for higher-than usual ambient dose rates in PS ring

PS Smoke Tests 2005



Environmental model



- A set of conservative models for
  - transport of radionuclides into and in the environment (by air and water, deposition, resuspension, uptake by crop and animals)
  - Exposure of representative group of public (irradiation, uptake)
- Estimated dose can be compared with appropriate limits

Dose from CERN releases (Meyrin site, 2008)

	Release* (GBq)	Dose (μSv)
Short-lived beta emitters	13240	3.05
Other $\beta\gamma$ (^{60}Co)	0.0092	0.22
Stray radiation	-	3.7
Total		**7.0**

- For comparison: Dose to reference groups at Swiss NPP:
  - PWR: < 1 μSv /y
  - BWR: 5 μSv /y

•PS underestimated
(non-representative sampling point)
•PSB, EAST, AD at present not monitored
•N-TOF 2009:
+5000 GBq, +1.1 μSv

Airborne releases are at the limit of the optimisation threshold. (10 μSv / y)

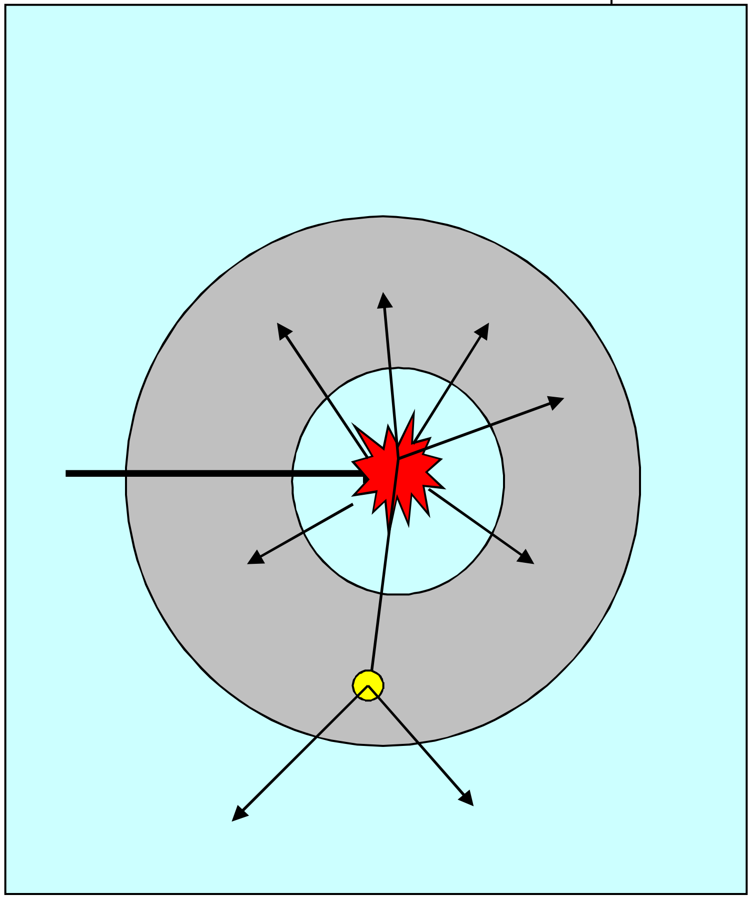
Any increase of releases will have to be justified and optimised

Reduction of air-borne releases

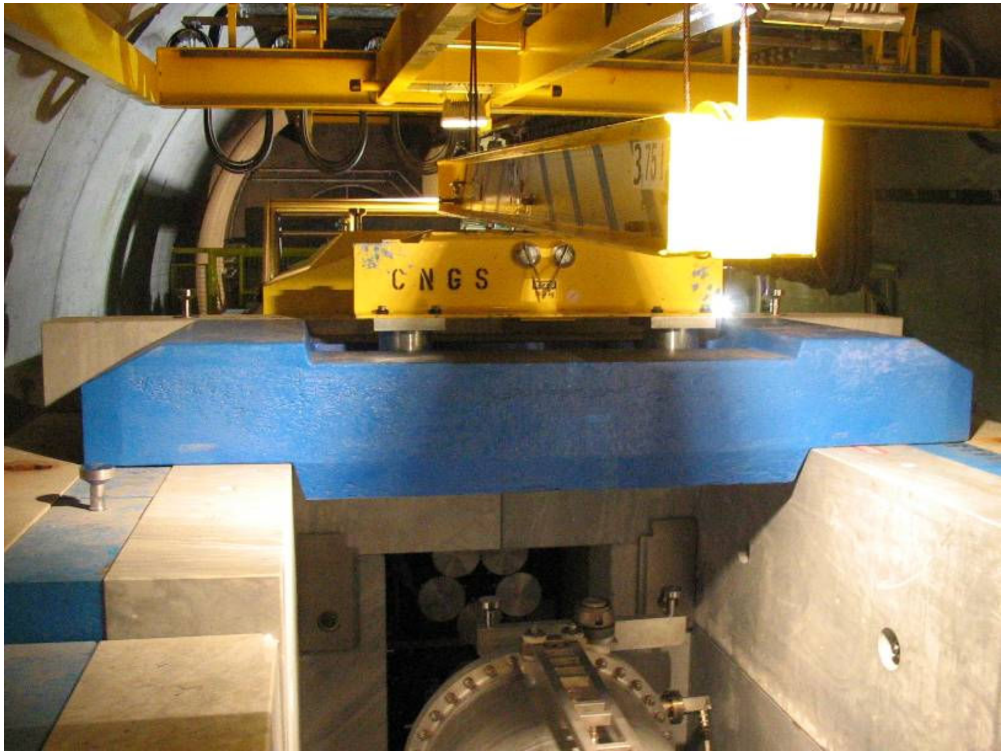
- Add shielding in target area
  - Reduce track length in air
- Closed ventilation system
  - Cool and dry air in closed circuit
  - Only vent before access
- Release from height
  - Construct a stack of h > 80 m

Shielding in target area

- Shielding absorbs secondary radiation cascade emerging from target
- Less activation of air
- Activation of shielding



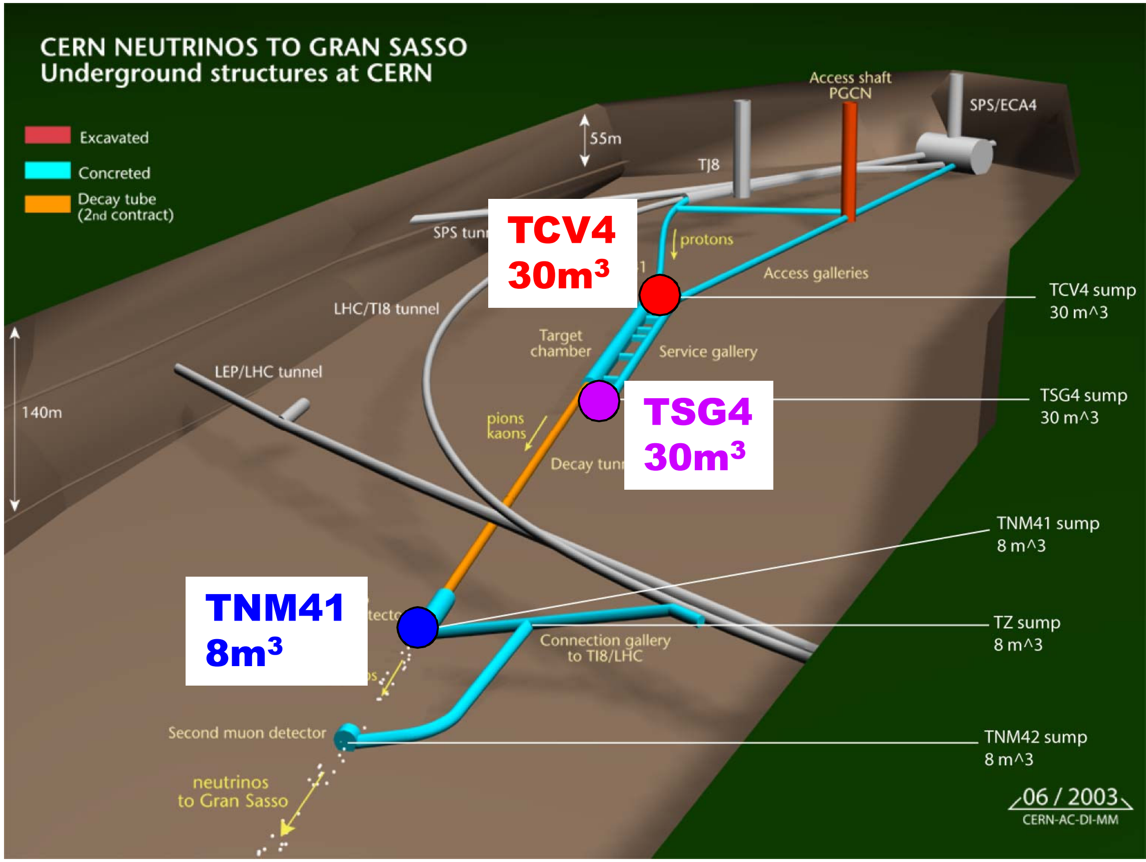
CNGS as an example



The target and horn are well shielded
Crane available for remote dismantling of shielding

Closed ventilation system

- Cool & dry activated air
  - “never” release
  - only before access
- Appears a good idea, but
  - Dynamic depression difficult to maintain
  - Accumulation of ^{3}H in condensate

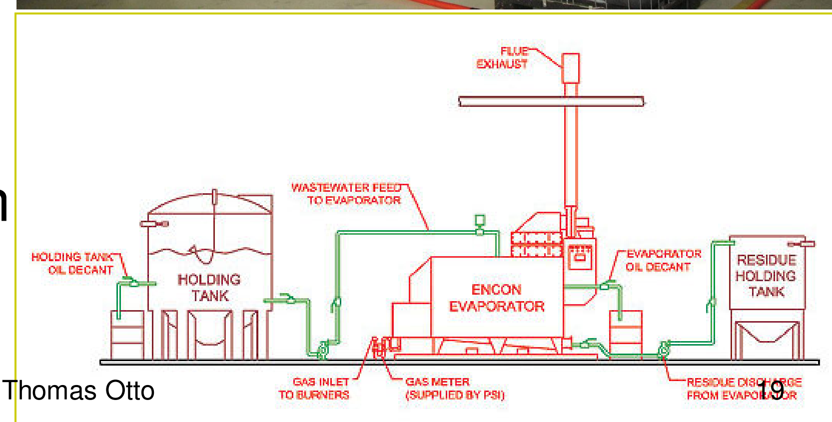


Tritium – where from ?

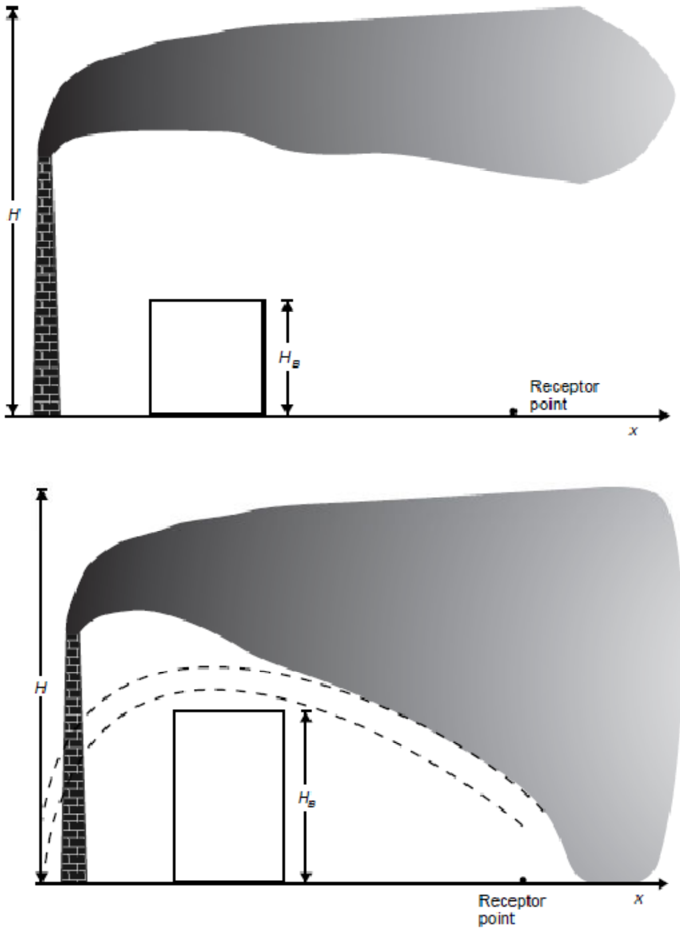
- Tritium is copiously produced as a light fragment in spallation reactions in (humid) air and in structural materials.
- It diffuses out of the walls in form of HTO
- In a closed ventilation system, the moist air is condensated in the dehumidifiers and the Tritium concentrated

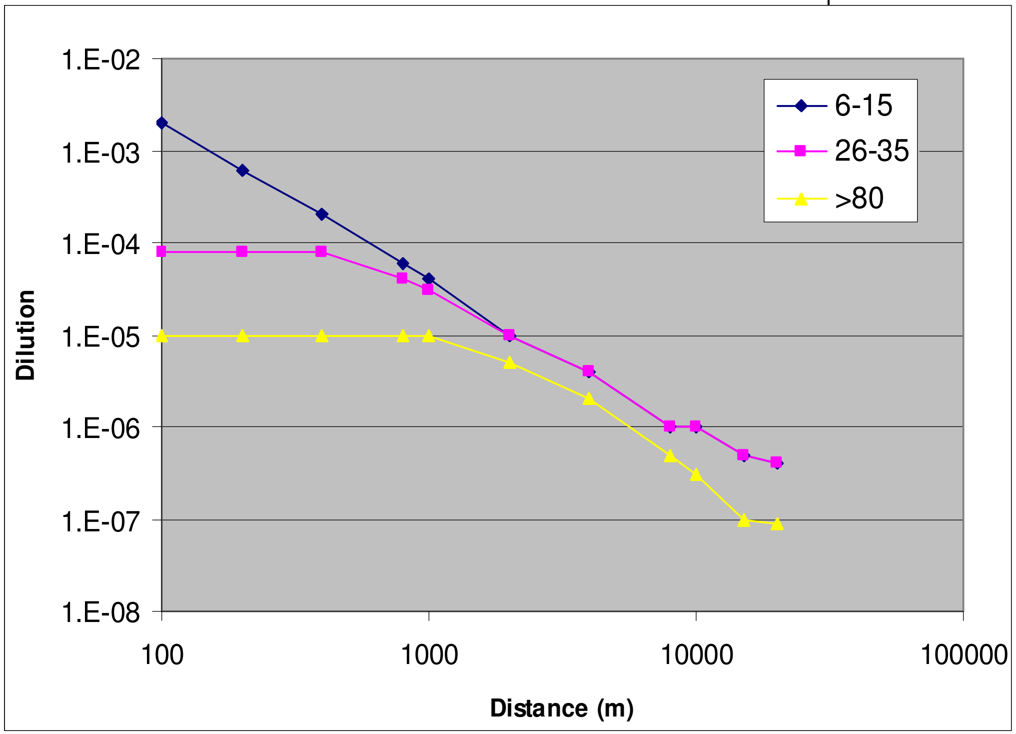
Consequence of CNGS – ^{3}H

- N-TOF 2008: “open” ventilation
  - The concentration of short-lived beta emitters allowed this solution
- Tritiated water
  - Storage in tanks
  - Elimination via nuclear site in France
  - Evaporation – the concentration in air is no reason to worry



Release from height (stack)





Diffusion (dilution) coefficient for radionuclide concentration as a function of stack height.

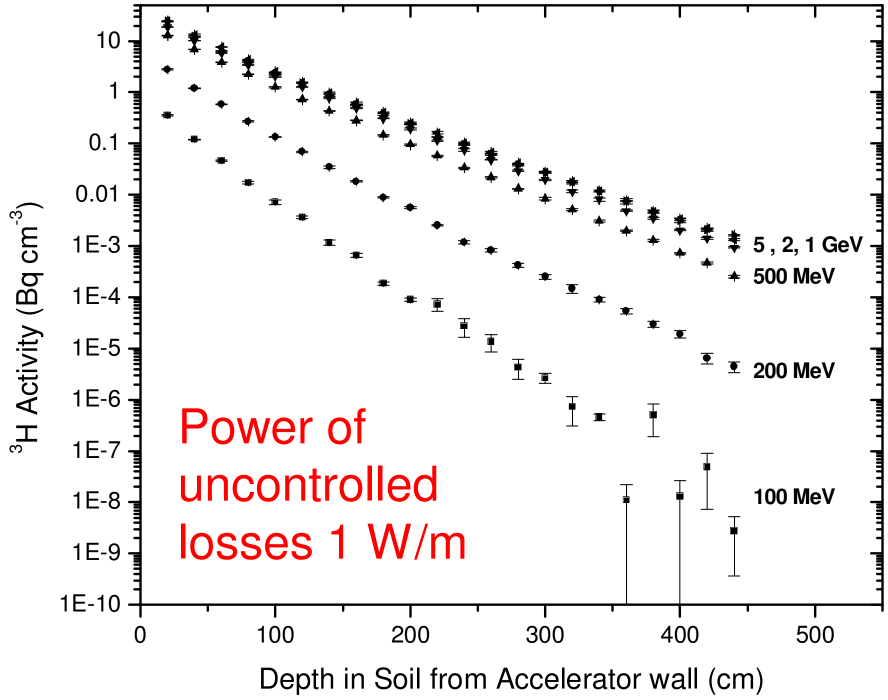
High stack affords orders of magnitude better dilution in the close zone (< 1000 m) !

Ground activation and ground water contamination

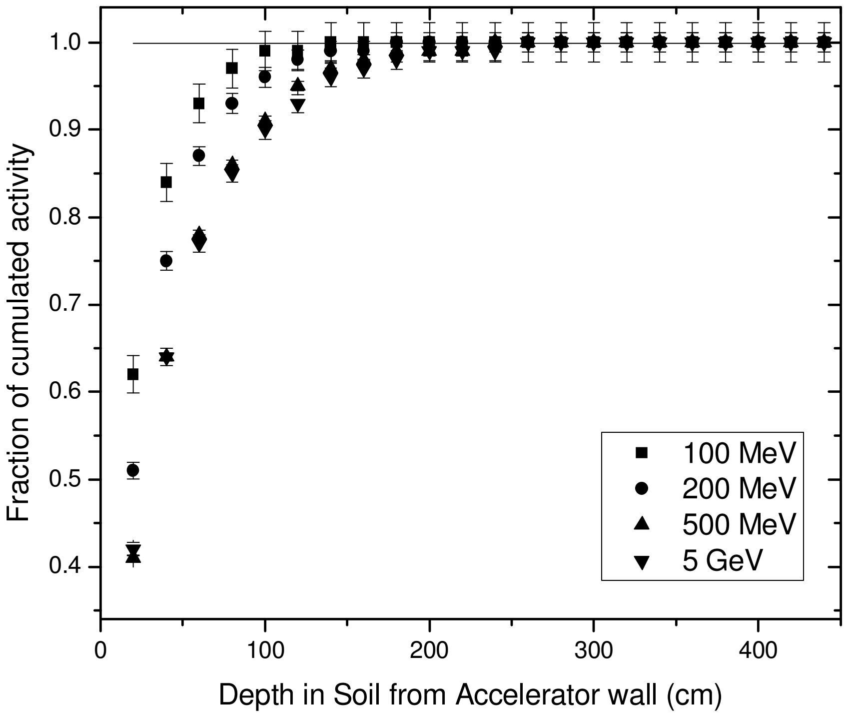
- Soil around accelerator is inevitably activated
- Activation may be fixed or unreachable for any human purpose (e.g. LEP / LHC)
- Activation migrates with ground water and runoff water
- Fermilab experiments (1980's):
  - ^{7}Be, ^{51}Cr, ^{22}Na, ^{54}Mn, ^{46}Sc, ^{48}V, ^{55}Fe, ^{59}Fe, ^{60}Co, ^{45}Ca and ^{3}H are produced
  - ^{22}Na, ^{3}H are soluble and easily transported

Distribution of activation

Lateral to proton accelerator tunnel:
Exp. activation profile, λ = 38 cm



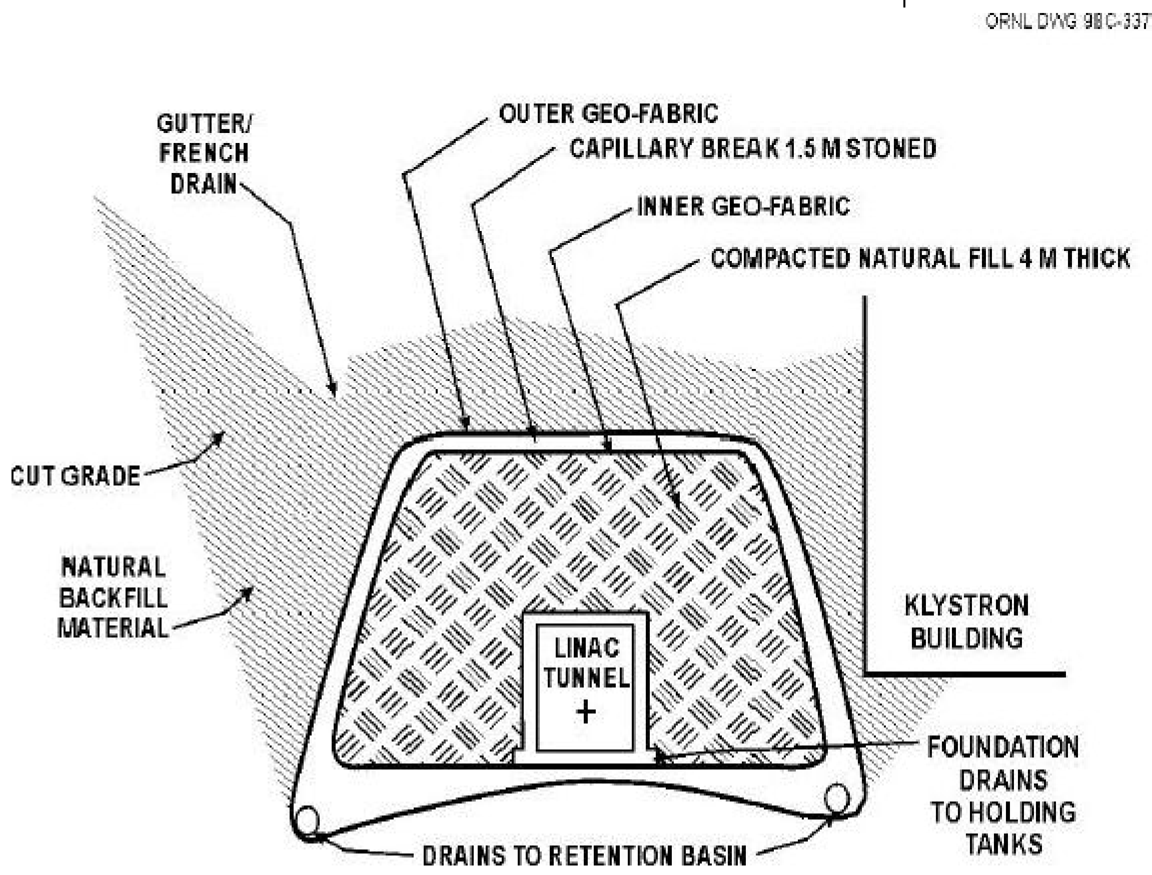
99.9 % of all activation is produced in a layer less than 3 m thick. ("activation zone")



Water from the activation zone is exceeding rad. waste levels for ^{22}Na and must be dealt with appropriately (infiltrations!)

Protective layers

- Drinking water resources outside the “activation zone” can be protected with a “geomembrane”
- (example SNS)



Situation at CERN

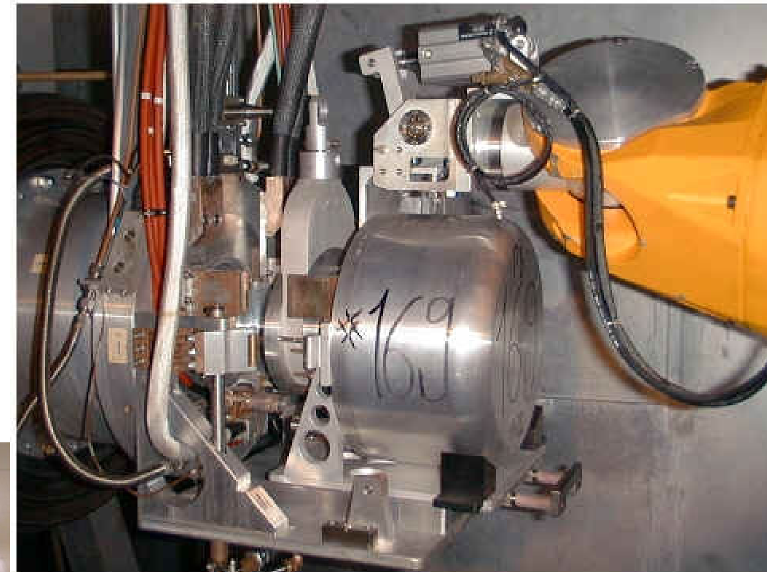
- Accelerators and target areas close to the surface (Linac, PSB,PS, East, AD, ISOLDE, n-TOF, North) are far from drinking water sourcing areas
- The potentially activated run-off must be diluted, in some cases in little streams with limited capacity
- Infiltration water in tunnels and target areas may be activated beyond free release guidelines

Waste from Target areas

- Most target areas produce one-off waste, e.g. the ISOLDE front-ends or the n-TOF target
- Highly activated, high ambient dose rate
- Find special agreements with national repositories for elimination and final storage

Waste from ISOLDE

- ISOLDE produces 30 waste target units per year
- High dose rate and actinide (alpha-emitter) content makes treatment in hot cell mandatory
- Temporary storage saturated
- Elimination pathway is required now



Summary

- Target areas have radiation protection topics in common
  - Activation, radioactive releases, waste production

- Imagine CERN increases beam power on targets:
  - Ventilation must be well-designed, air-flow fully understood
  - Release close to ground reaches its limits
    - closed circuit, high stack, shielding: no “silver bullet”
  - Ground activation becomes an issue for close-to-surface accelerators
  - Target areas produce highly activated waste
    - Suitable interim storage and elimination pathways must be defined