Radiation Protection Aspects of the Commissioning and Operation of CERN High Energy Accelerator Mixed Field (CHARM) facility in the CERN East Experimental Area

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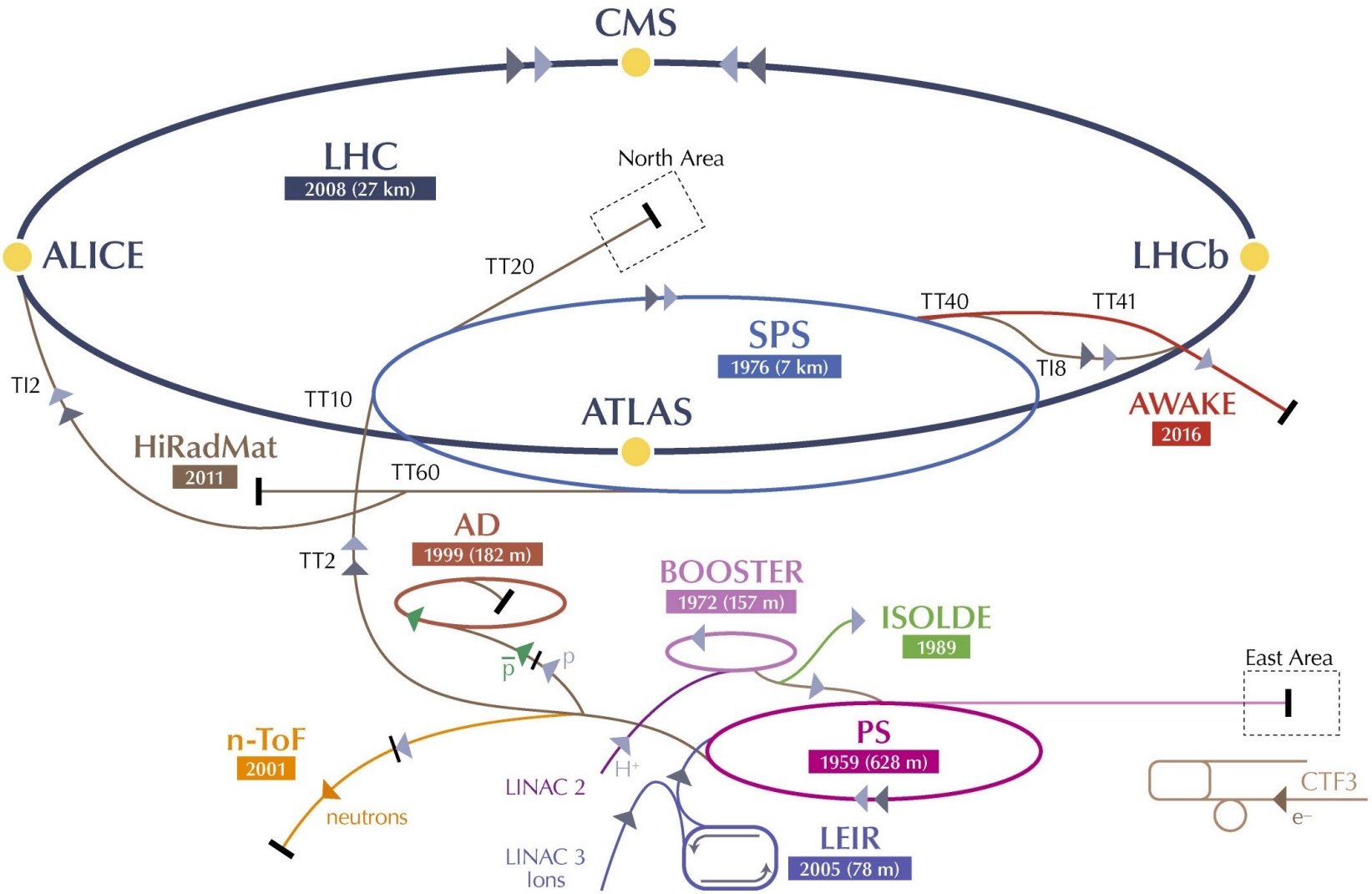
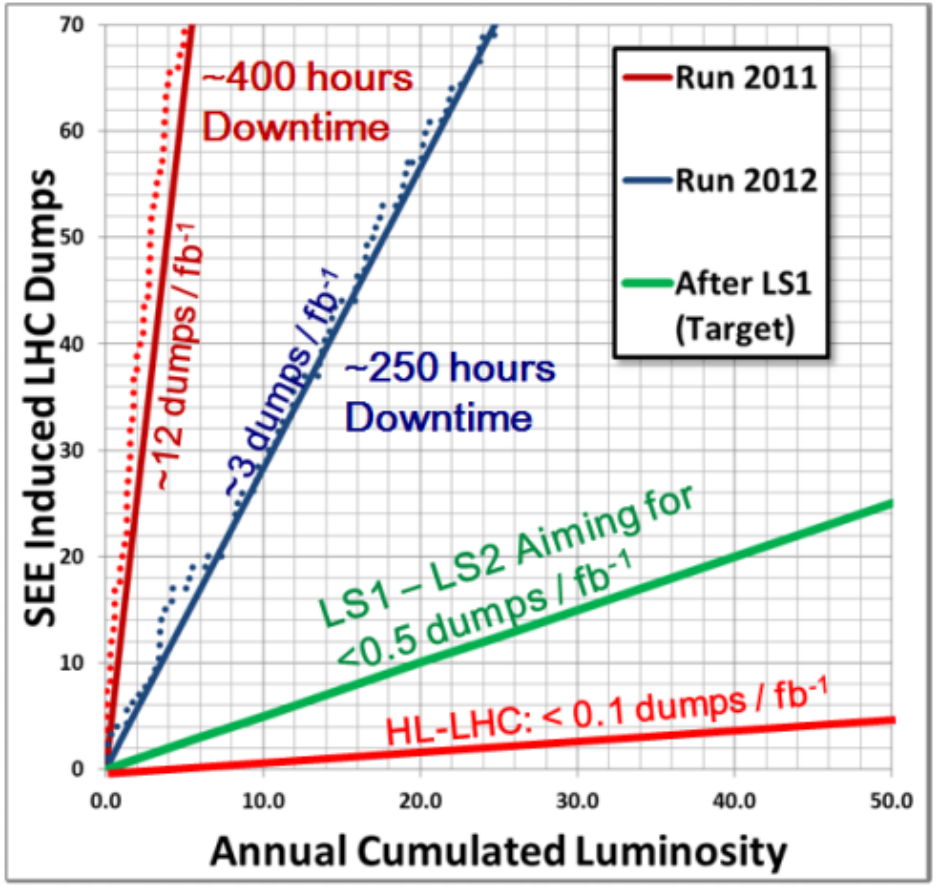
CERN Accelerator Complex

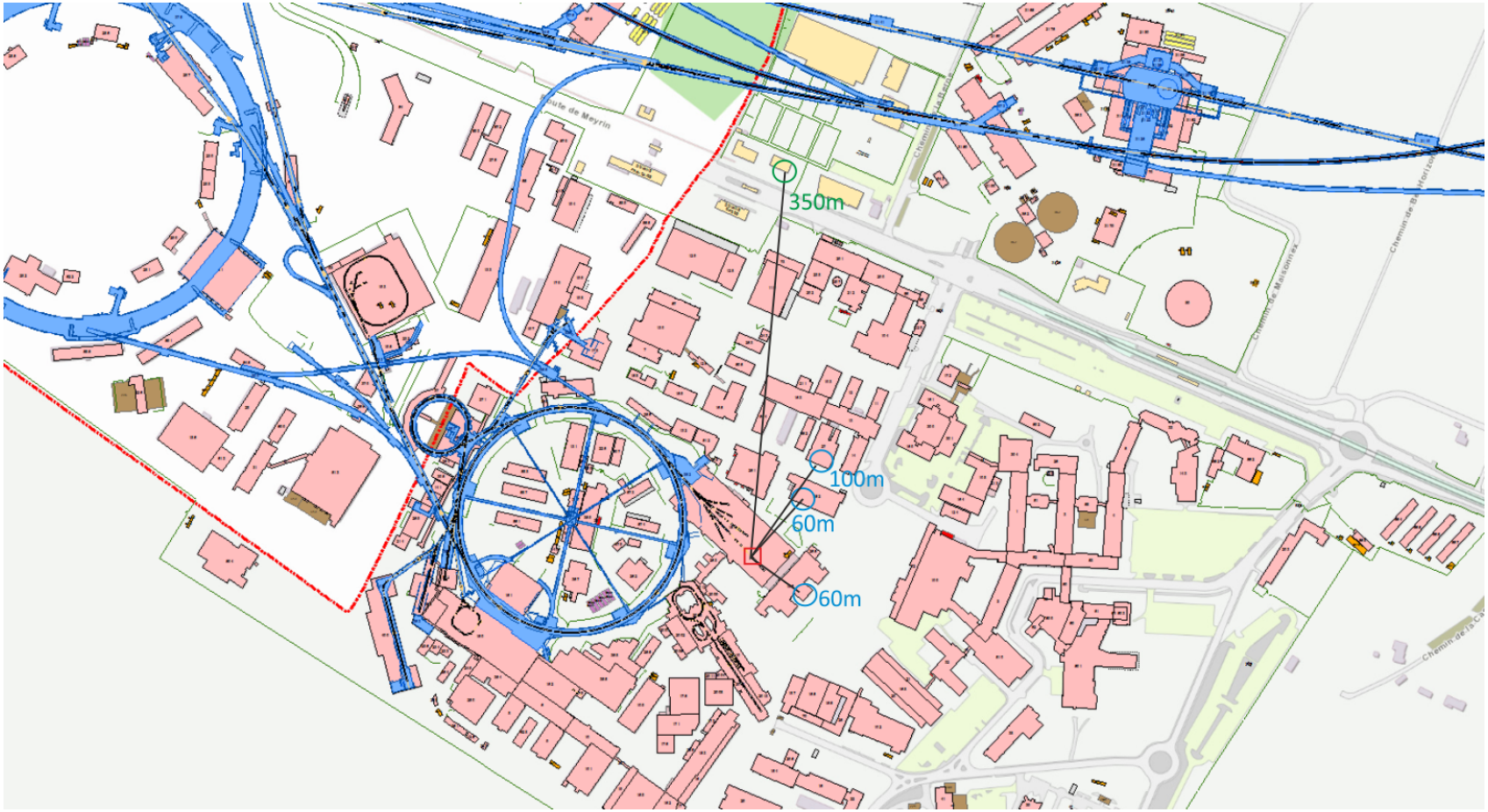


Motivation

- Objective of R2E project (Radiation2Electronics):
  ≤ 0.5 dumps per fb^{-1}
- Radiation test for electronic equipment (power converters, electronic devices)
- CHARM project to provide test locations with well understood, typical mixed radiation fields
  (in addition to existing facilities CNGS, CERF, H4IRRAD, IRRAD)
- Space in CERN–PS East Experimental Hall available due to decommissioning of DIRAC experiment in 2013
- Design and construction during the Long Shut-down 1 (2013-2014)



Location

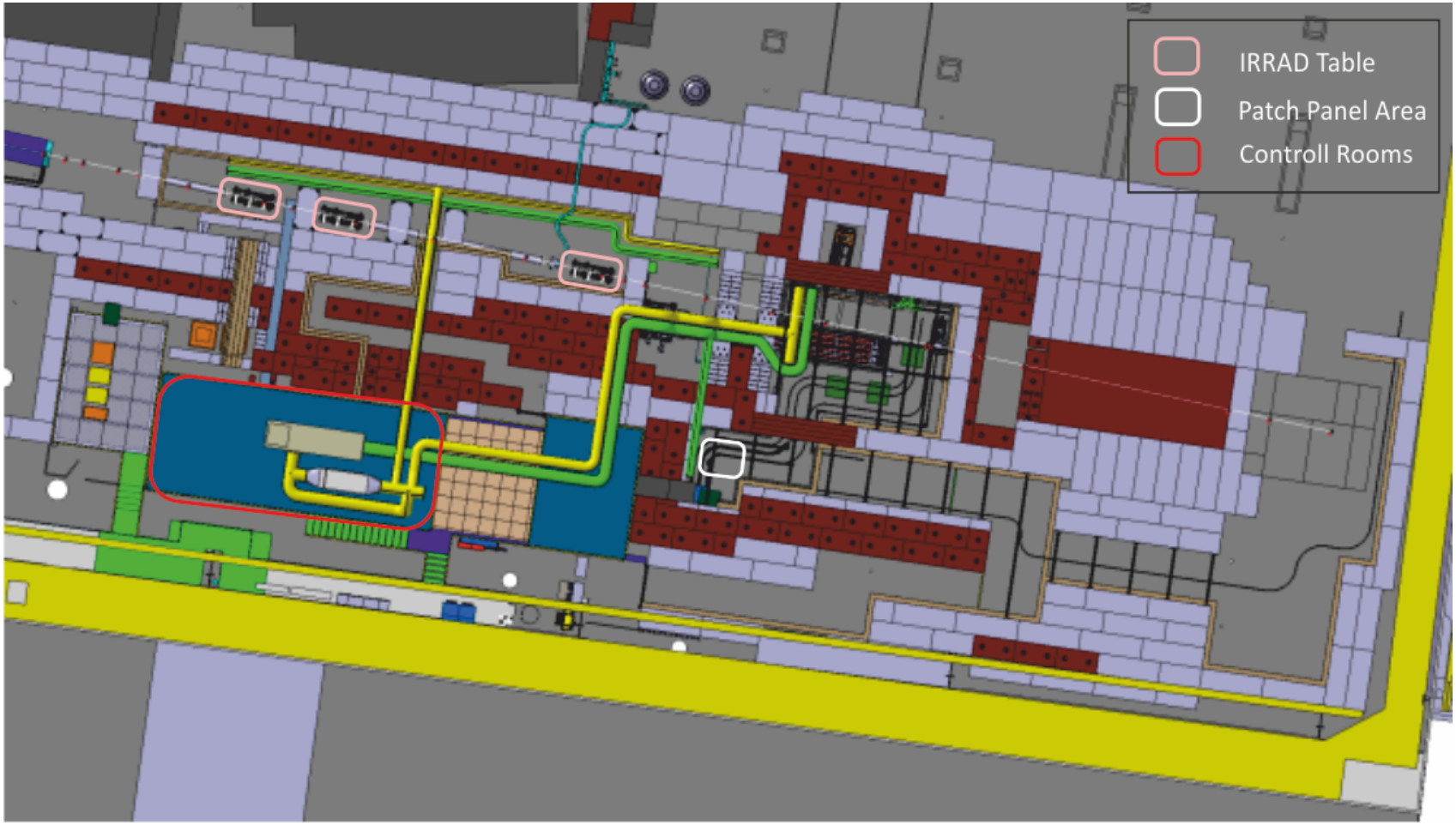


Parameters

- Proton beam from CERN–PS with 24 GeV/c on target
  - up to 5e11 protons/pulse
  - Pulse length 350 ms
- Three targets for CHARM to adjust intensity
  - Copper
  - Aluminum
  - Aluminum with longitudinal slits to reduce effective density
  - Diameter 8 cm, length 50 cm

Scenario	Number of spills per super-cycle (45.6 s)	Proton beam intensity Average	Proton beam intensity Annual
Nominal	2	2.2e10 p/s	3.3e17 p/y
Maximum	6	6.6e10 p/s	1e18 p/y
e-Cal	1	7.5e9 p/s	9e15 p/y
h-Cal	1	1.1e10 p/s	7.3e15 p/y

Integration – IRRAD & CHARM



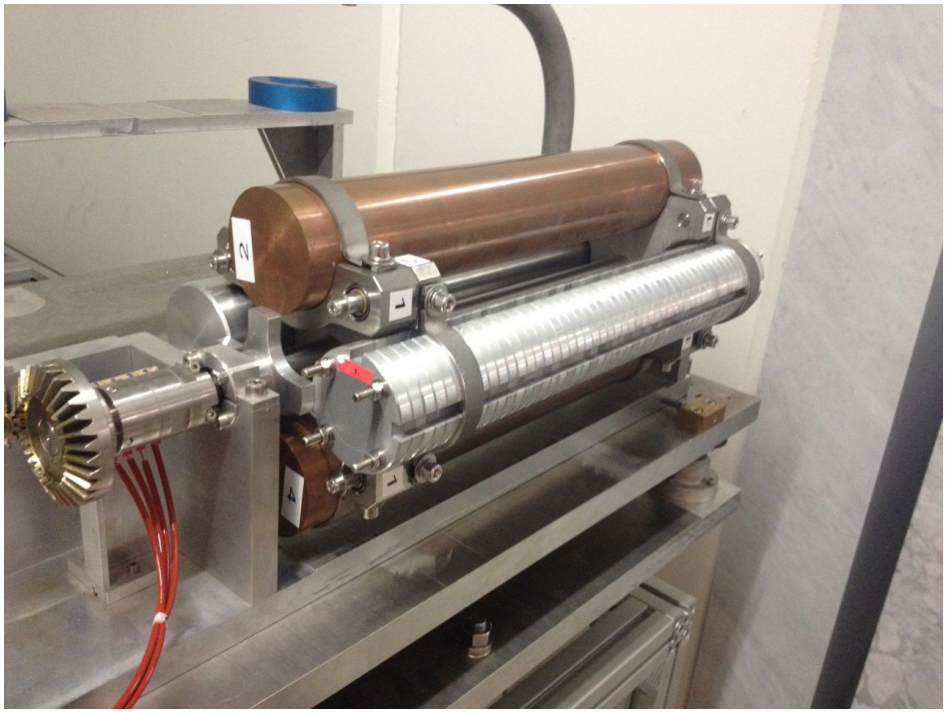
Radiation Protection Assessment

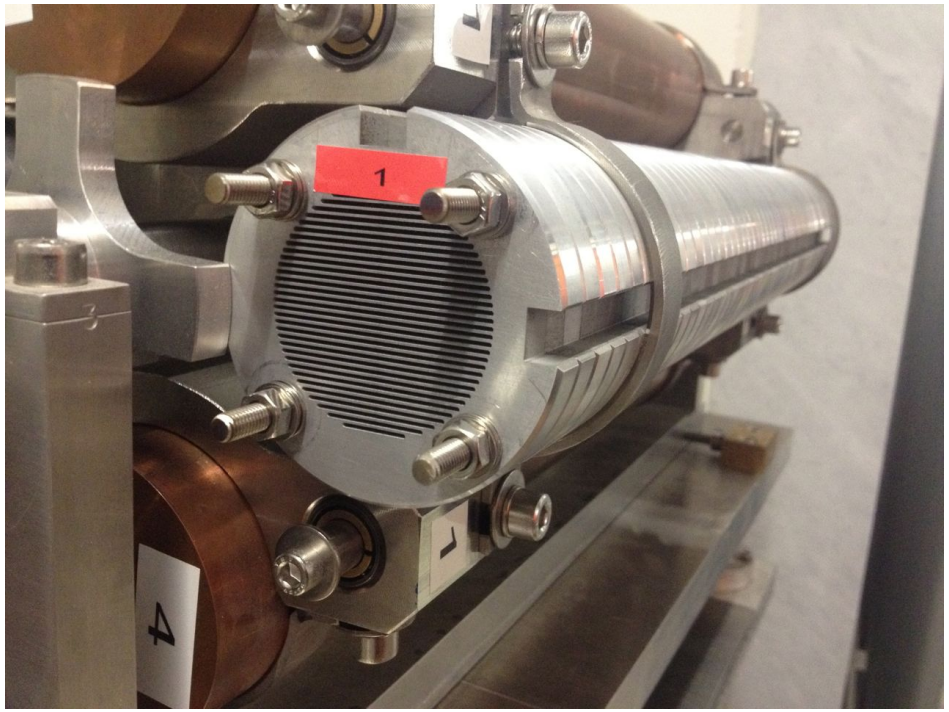
- Radiation Protection Assessment during the design phase
  - Prompt radiation
  - Residual radiation
  - Air activation
  - Environmental impact
- presented at SATIF 12, 2014, Fermilab
- Froeschl, R., Brugger, M., Roesler, S., *The CERN High Energy Accelerator Mixed Field (CHARM) facility in the CERN PS Experimental Area*, SATIF-12 Proceedings, Fermilab, 2014.
- Froeschl, R., *Radiation Protection Assessment of the Proton Irradiation facility and the CHARM facility in the East Area*, CERN-RP-2014-008-REPORTS-TN (2014).

Construction and Commissioning

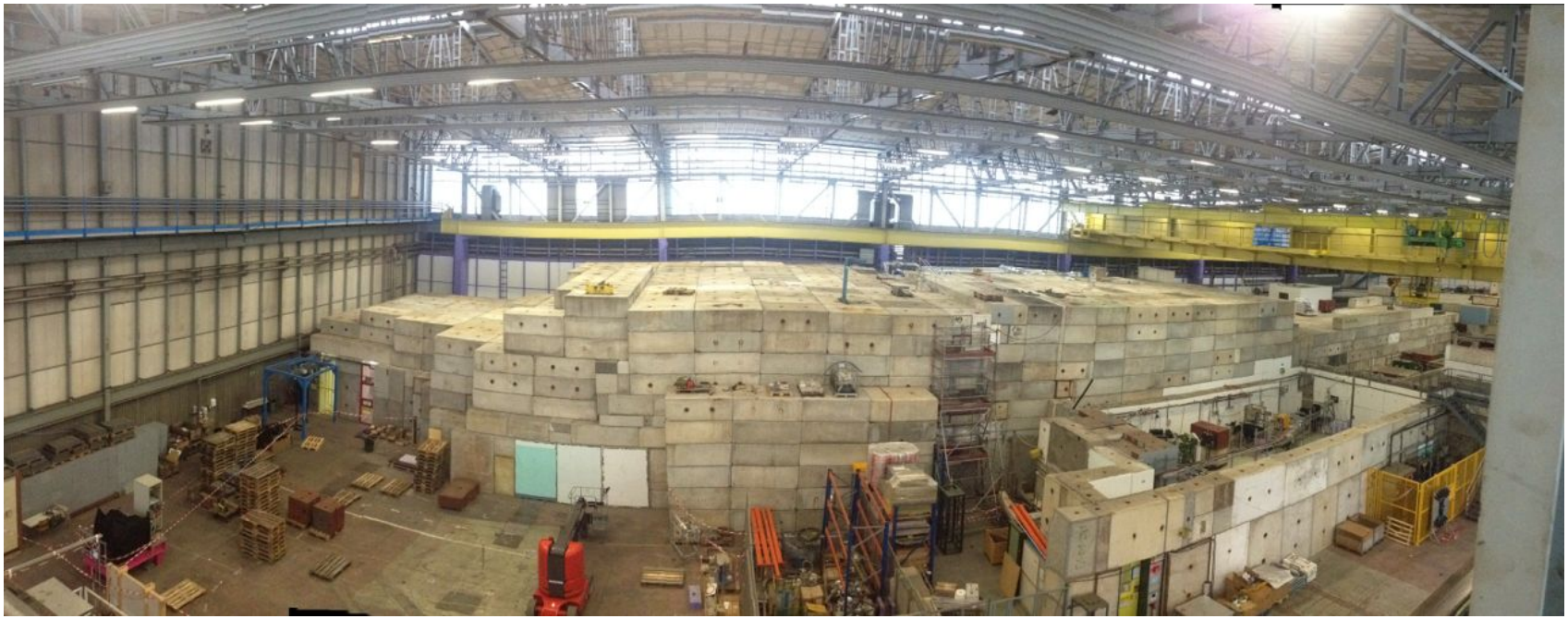
- Construction in 2013-2014 during the Long Shut-down 1
- Close collaboration with integration team during the construction process
- Commissioning with tight cooperation of operation teams using a gradual approach
- Verification of shielding and residual ambient dose equivalent rates in dedicated measurement campaigns

CHARM Targets





Shielding Construction



Radiation Protection Monitoring

- AMF/AGM for prompt radiation
- IAM for residual radiation
- VMS for monitoring the release to the environment
- Mobile AMF/AGM during commissioning
- Supervision and data extraction/analysis via dedicated GUI

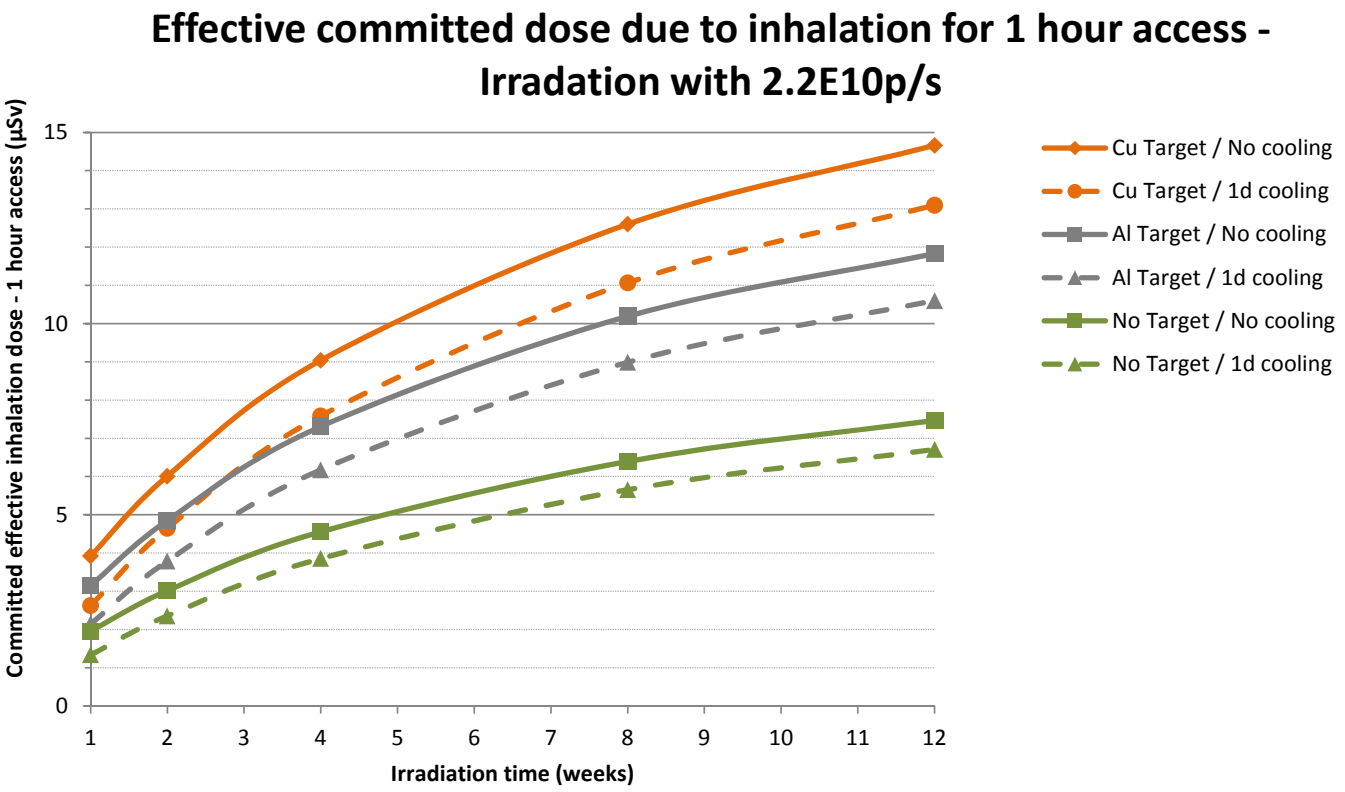
Radiation Protection Monitoring

Shielding with final RP Monitor placement

Commissioning without ventilation system

- Ventilation system had not been operational during start-up phase
  - No flush before access possible
  - No extraction during beam operations
    - Different build-up of the radionuclides (effective half-life changed)
- Reduction of average beam intensity or restriction on target choice as a function of the operation time to respect design constraint of 1 μSv committed effective dose due to inhalation for a 1 hour long access

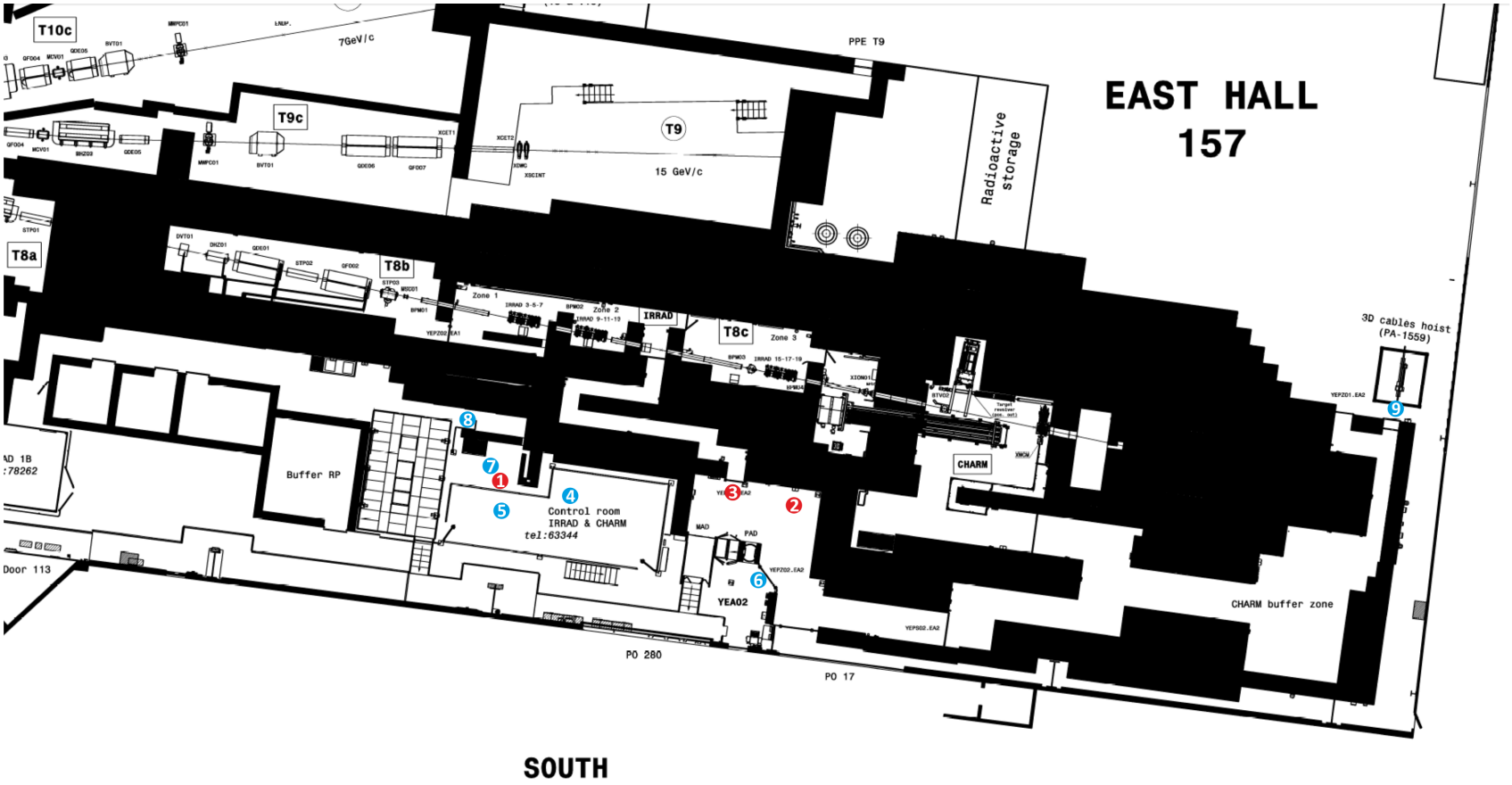
Commissioning without ventilation system



Verification

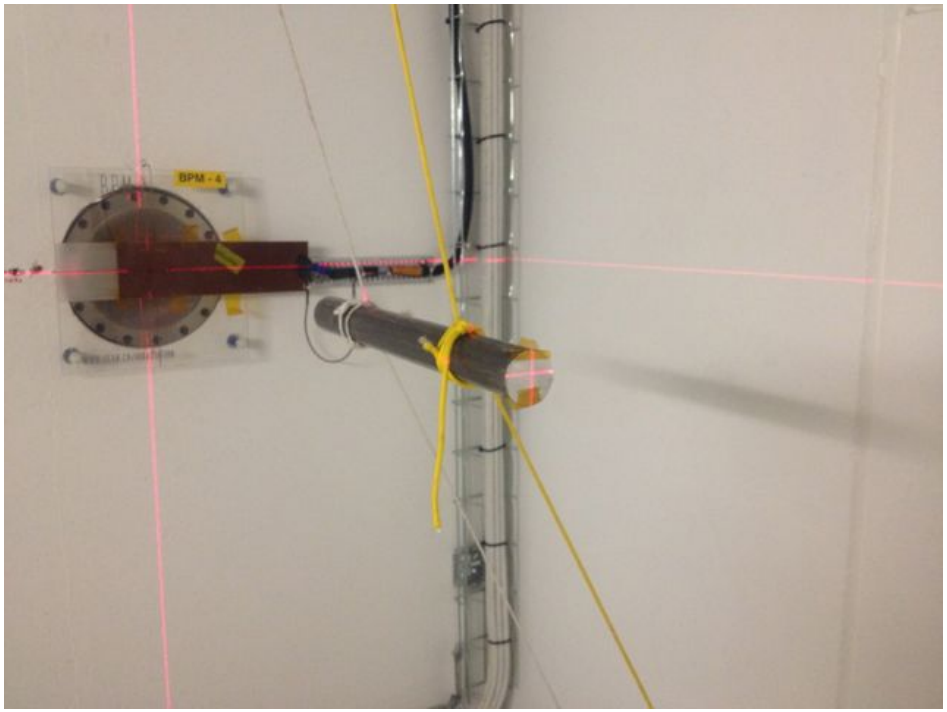
- Permanently installed RP monitors
- Dedicated measurement campaigns including mobile RP monitors
- Comparison to Monte Carlo simulation results

Verification – Campaign 1

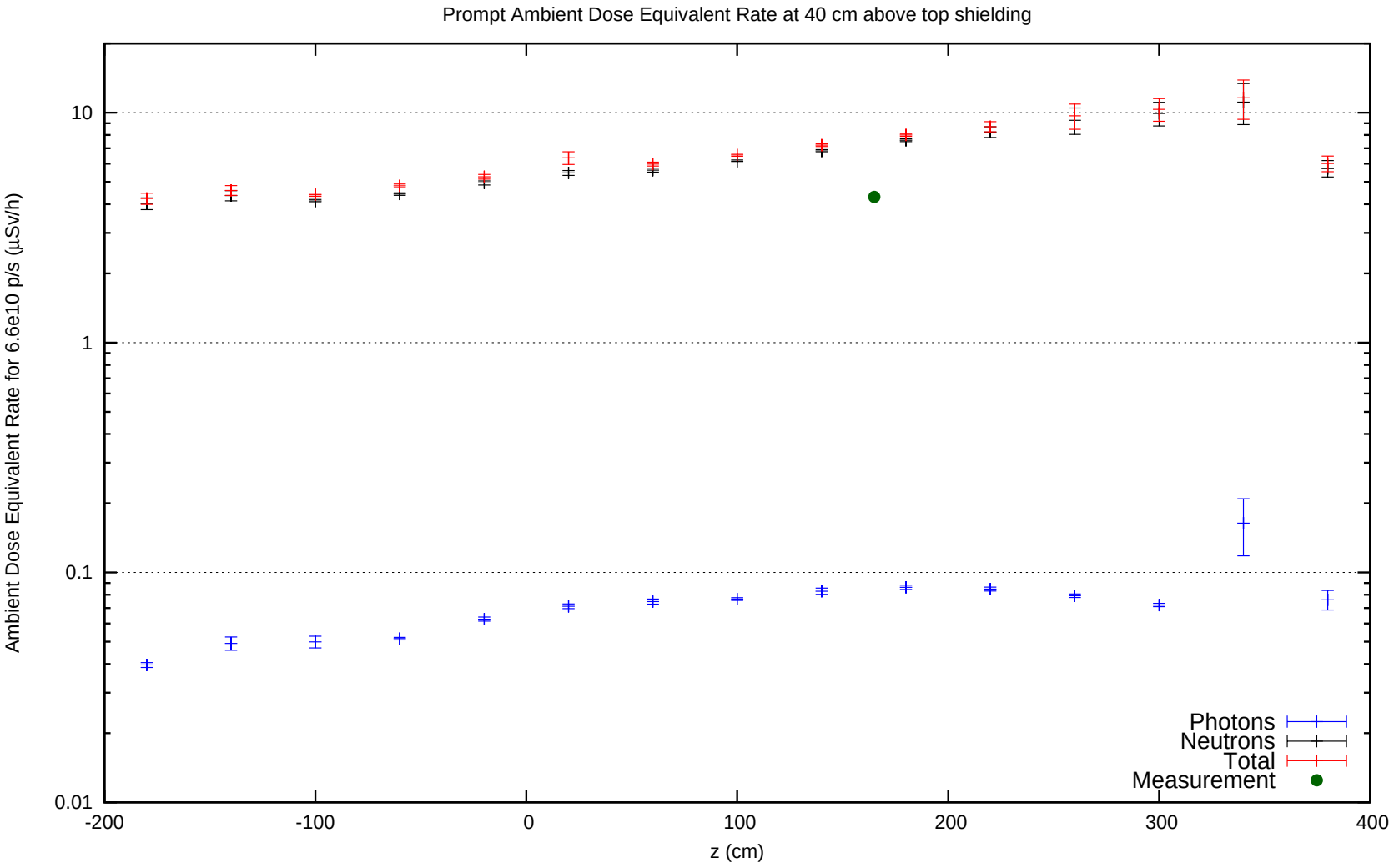


Verification – Campaign 2

Verification – Campaign 2

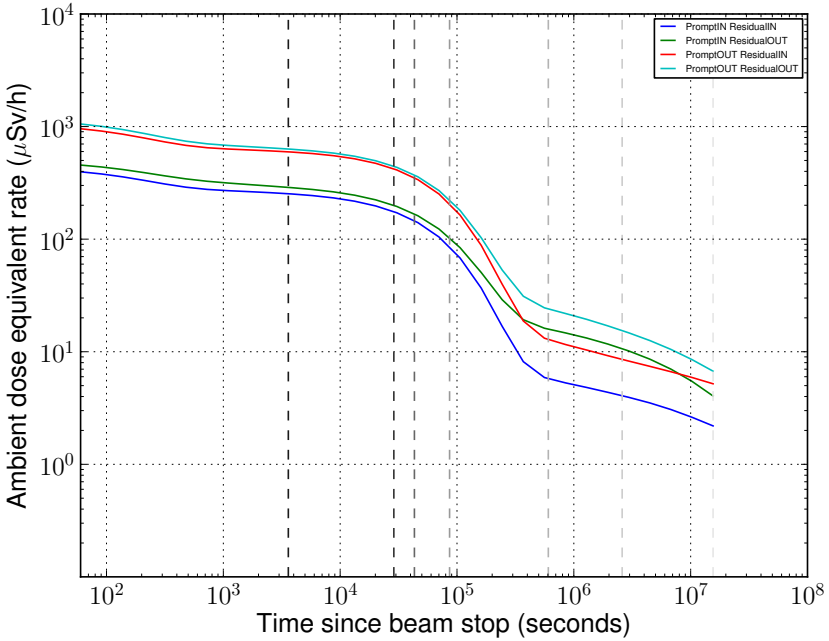


Verification – Campaign 3



Verification – Induced Activation

- Residual ambient dose equivalent rates
  - Permanently installed RP monitors
  - Dose rate surveys
  - Measurement data collection for residual ambient dose equivalent rates benchmark (FLUKA/DORIAN) at the beginning of the winter technical stop 2015/16 (45 minutes up to 2 weeks)
- Activation samples

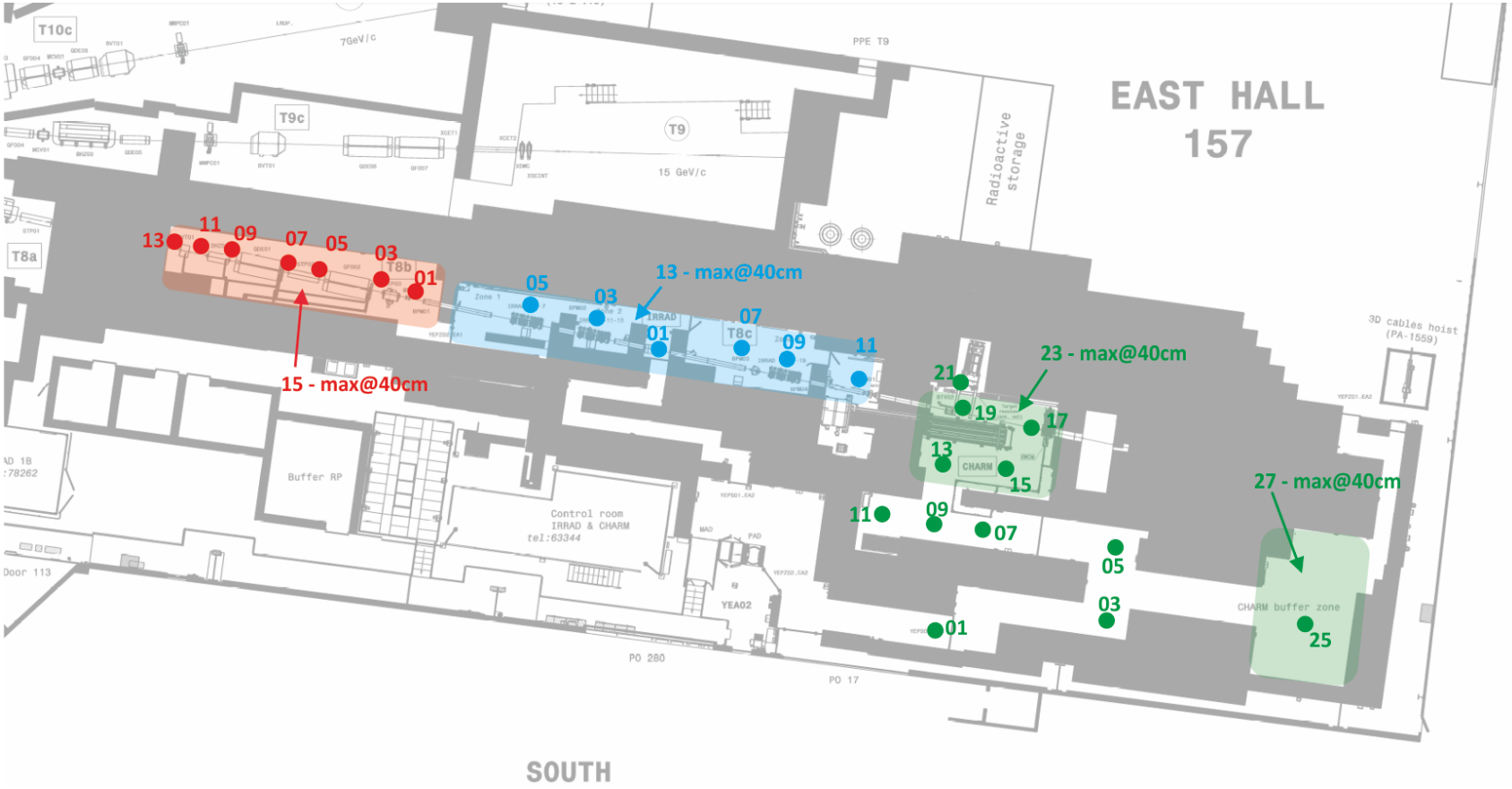


Access planning and operational dosimetry

- Procedure for target removal before access as a function of facility exploitation
- Flush by ventilation system before access
- Access planing and coordination is extremely important for efficient and optimized operation
- Operational dosimetry system linked with work planning tool and quick feed-back to guide optimization process
- Residual Radiation Survey

Average Beam Intensity I	Required cool-down time before access		
	Copper target		Al/Al sieve target
(protons/h)	Mobile Shielding Retracted	Mobile Shielding Inside	
$I < 9e13$	3 hours	3 hours	3 hours
$9e13 \leq I < 1.3e14$	12 hours	3 hours	3 hours
$1.3e14 \leq I$	24 hours	12 hours	3 hours

Residual Radiation Survey – Definition



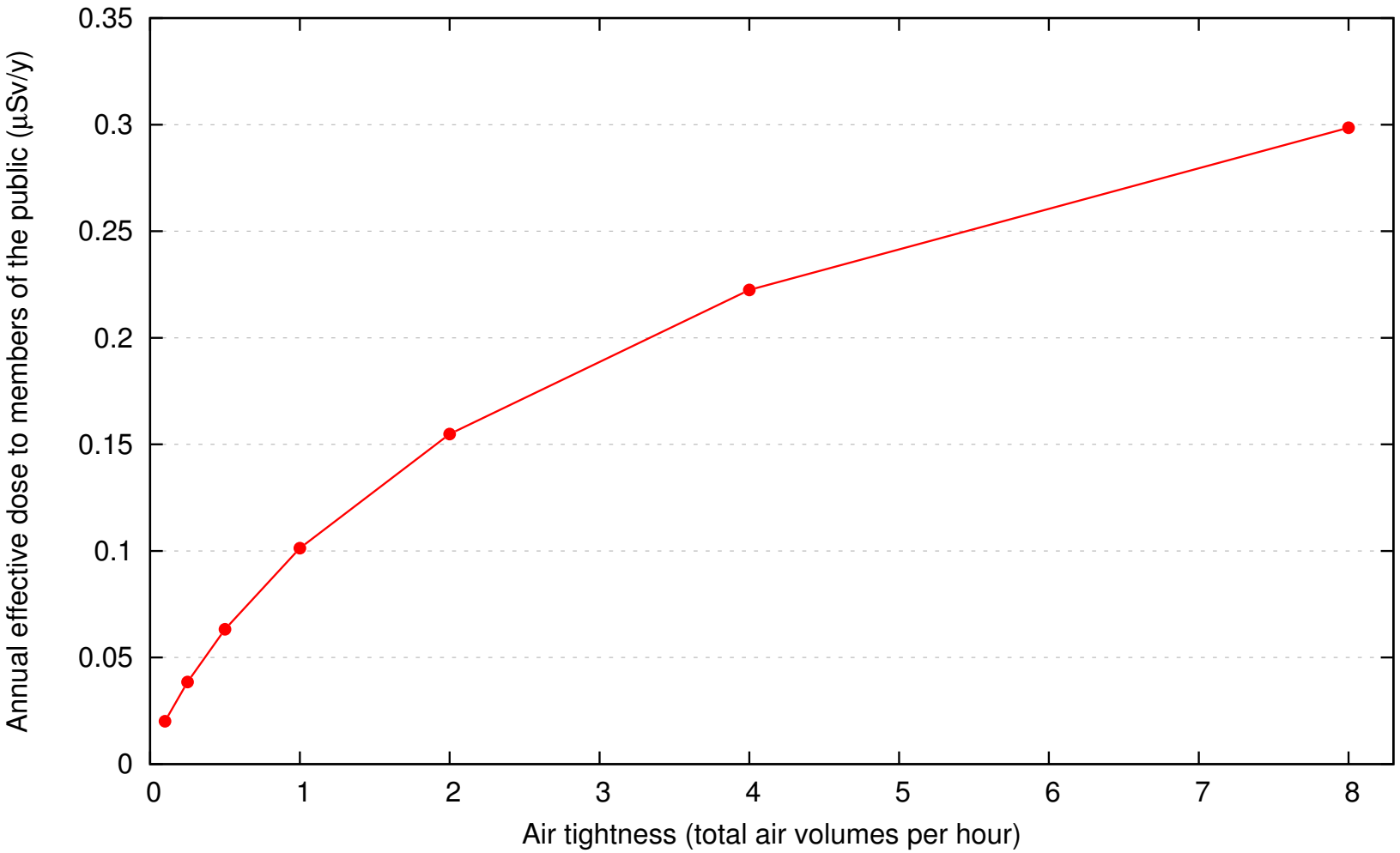
Residual Radiation Survey – Example

Operation in 2015

- Operation period from April to November 2015
- Number of protons slightly below nominal design value
  - Beam attribution has been adapted for operation in 2016
- Air exchange rate of 6.7 volumes/hour

Target type	Number of protons in 2015
Aluminum sieve	1.30e16
Aluminum	7.20e15
No target	2.38e14
Copper	2.71e17

Derived Design Goal on Air Tightness



Effective dose to members of the public in 2015

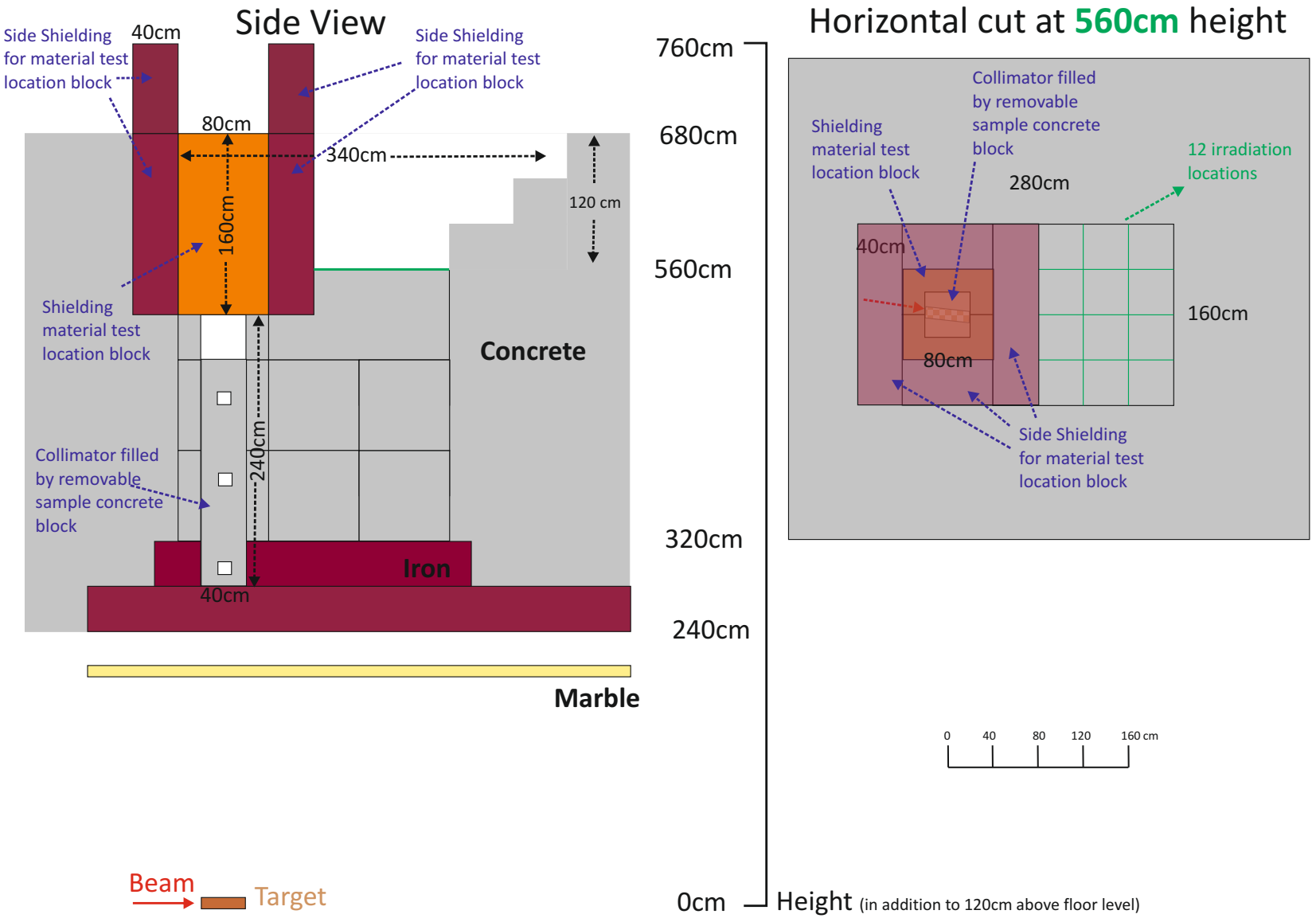
- Airborne Release: 0.084 μSv/y
- Sky-shine 0.58 μSv/y
  - Calculations scaled by
    - number of protons per year
    - ratio of ambient dose equivalent rate on roof between measurements and FLUKA simulations
- Total 0.66 μSv/y
- Below design goal of 1 μSv/y

Radionuclide	Release		Eff. dose
	Total (TBq/y)	Fraction	(μSv/y)
C-11	0.33	0.14	0.017
N-13	0.79	0.35	0.030
O-14	0.08	0.04	0.002
O-15	0.99	0.44	0.013
Ar-41	0.06	0.03	0.005
Total predicted	2.28		0.075
Measured	2.54		0.084

CERN Shielding Benchmark Facility

- Combined facility of EN/EA, R2E and RP
- Characterization of the shielding properties of various materials
- Deep shielding penetration studies
- Detector calibration
- Detector inter-comparison
- Activation benchmarks
  - see presentation by E. Iliopoulou et al. on Wednesday
- Situated laterally above the CHARM target
  - Dedicated use for 1 week per year
  - Parasitic use of the radiation field emerging from the CHARM target during normal CHARM operation

CSBF Upgrade



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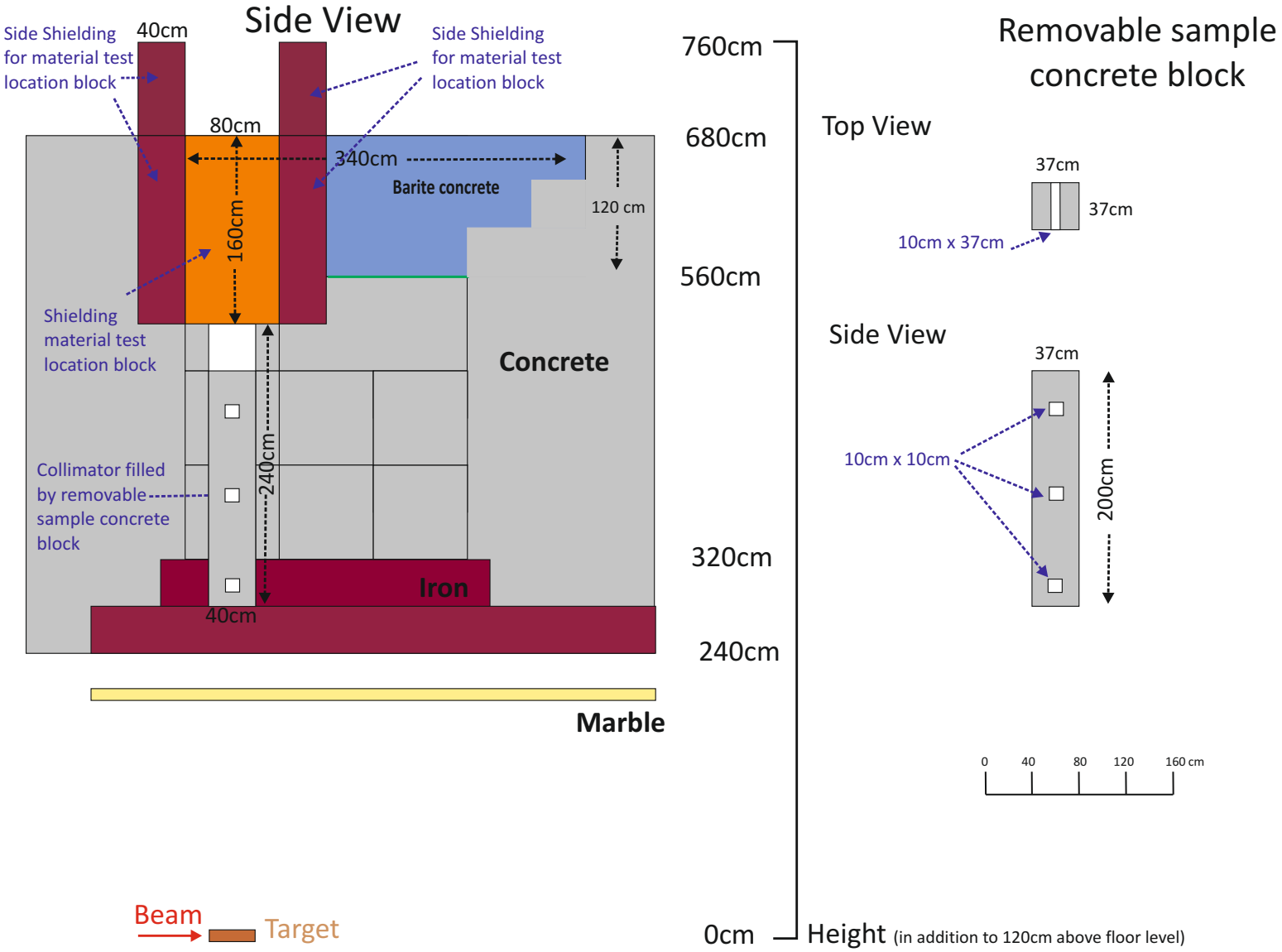

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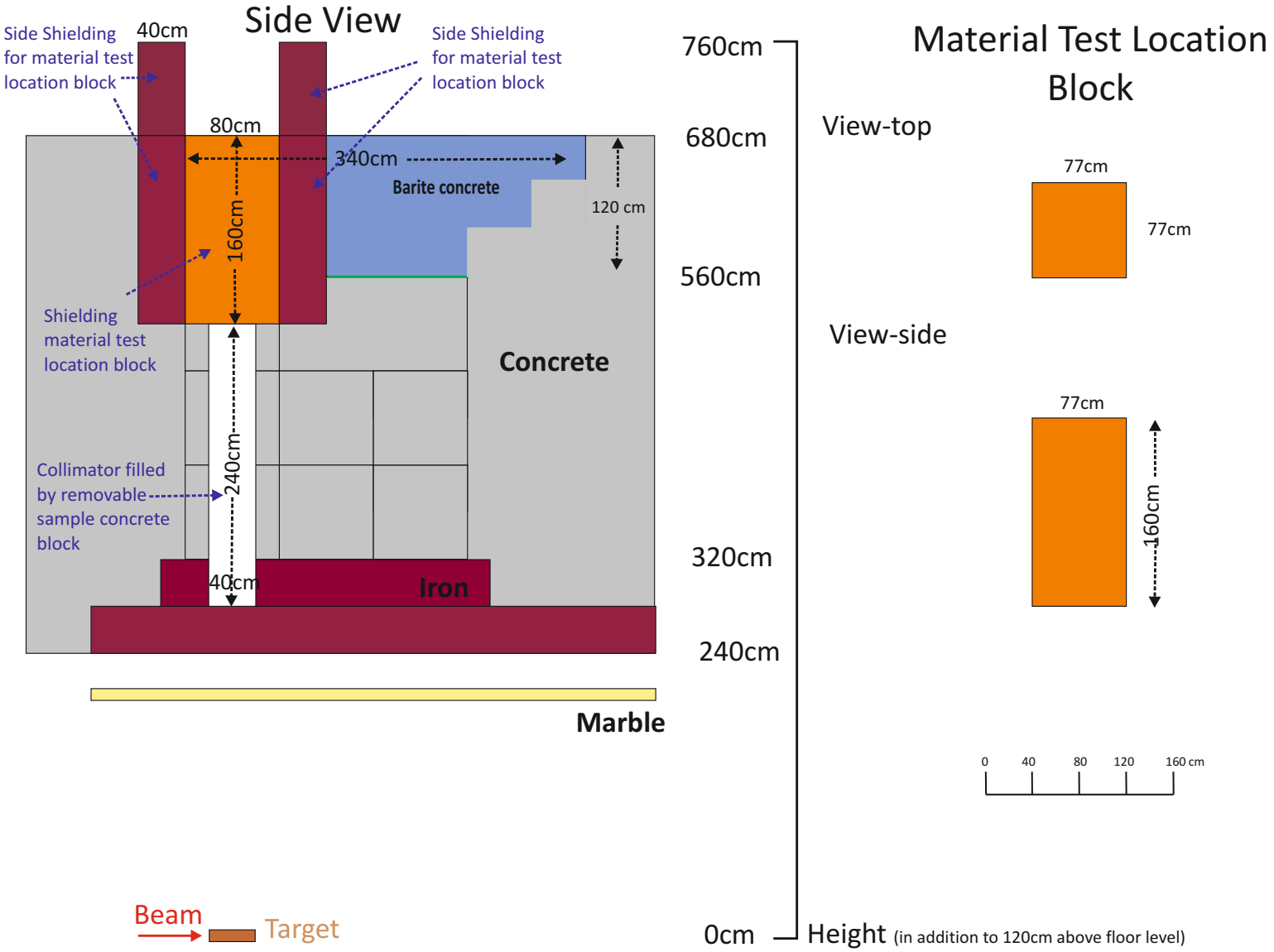

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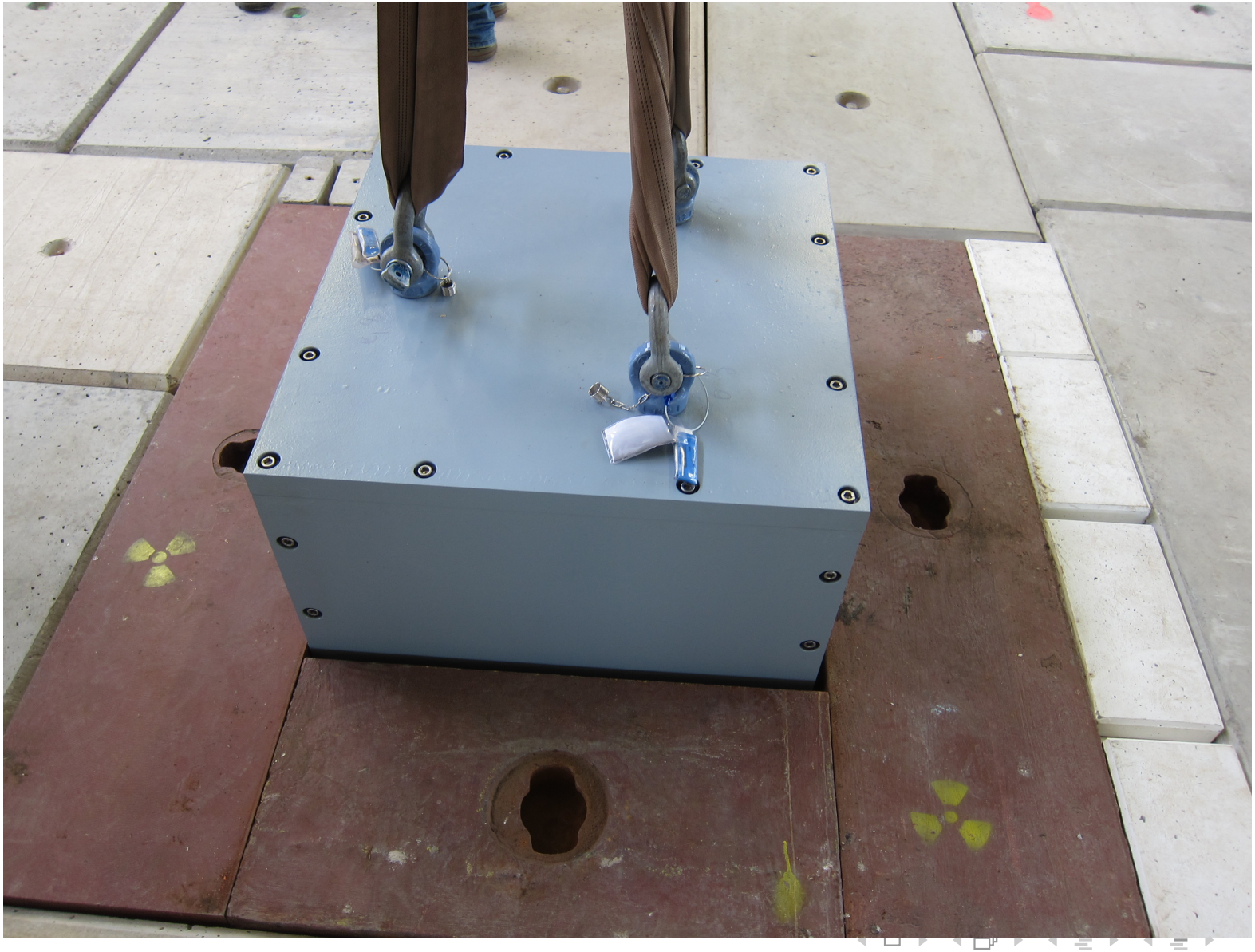

Conclusions

- CHARM facility has been constructed and commissioned in 2014
- Shielding design, residual dose rate and air activation estimates have been verified
- CHARM (and IRRAD) fully operational for their design limits since December 2014
- Optimization for operational exploitation well advanced
- CERN Shielding Benchmark Facility upgraded in 2016
- On the agenda
  - Evaluation of CSBF run in 2016 and planning for 2017
  - Evaluation of residual dose rate benchmark data

Acknowledgments

- Experimental Area group
- Integration team
- IRRAD & CHARM operation teams
- Transport group
- Gamma spectrometry laboratory

Backup

Thank you
for your attention!

Backup

Backup

CSBF Upgrade

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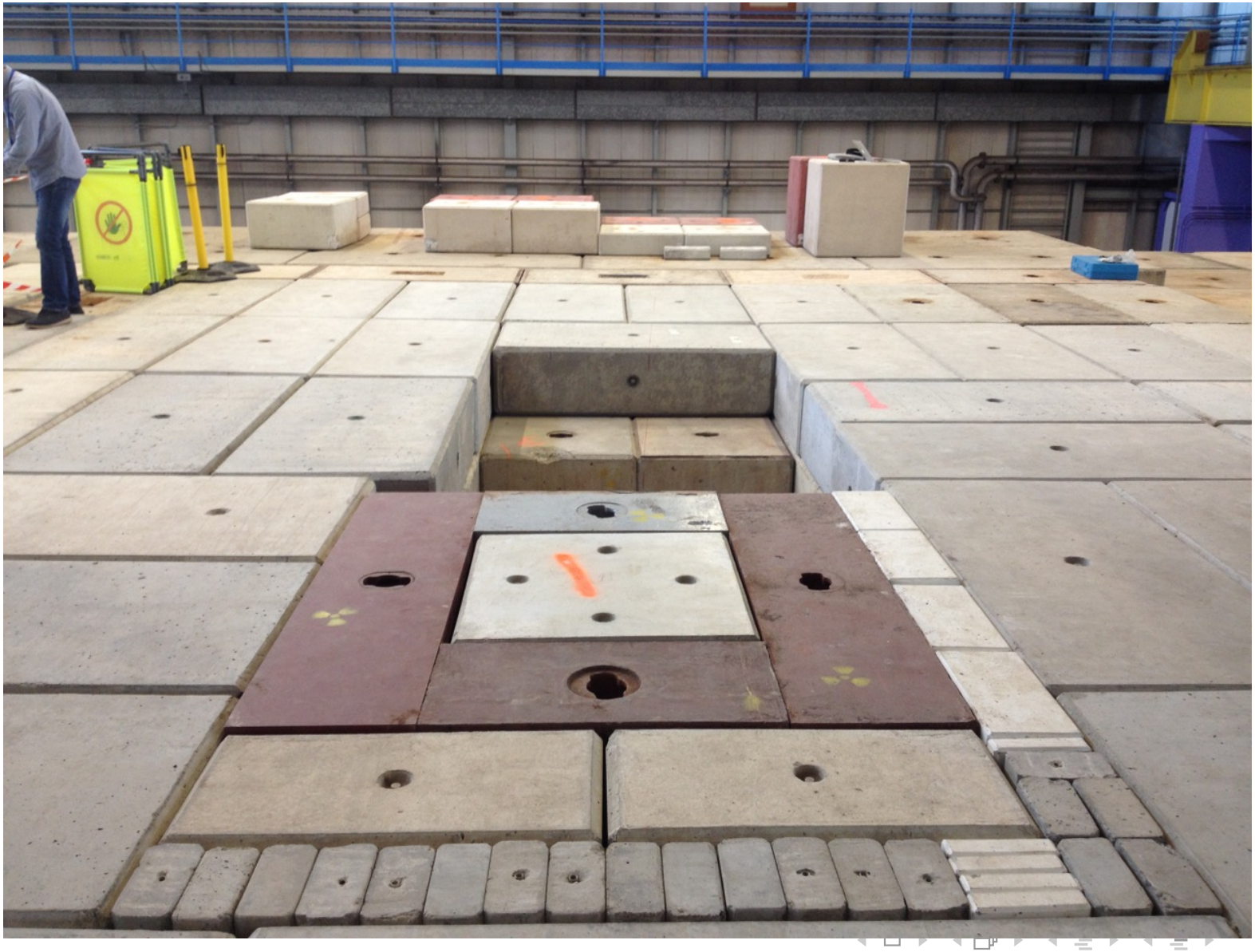

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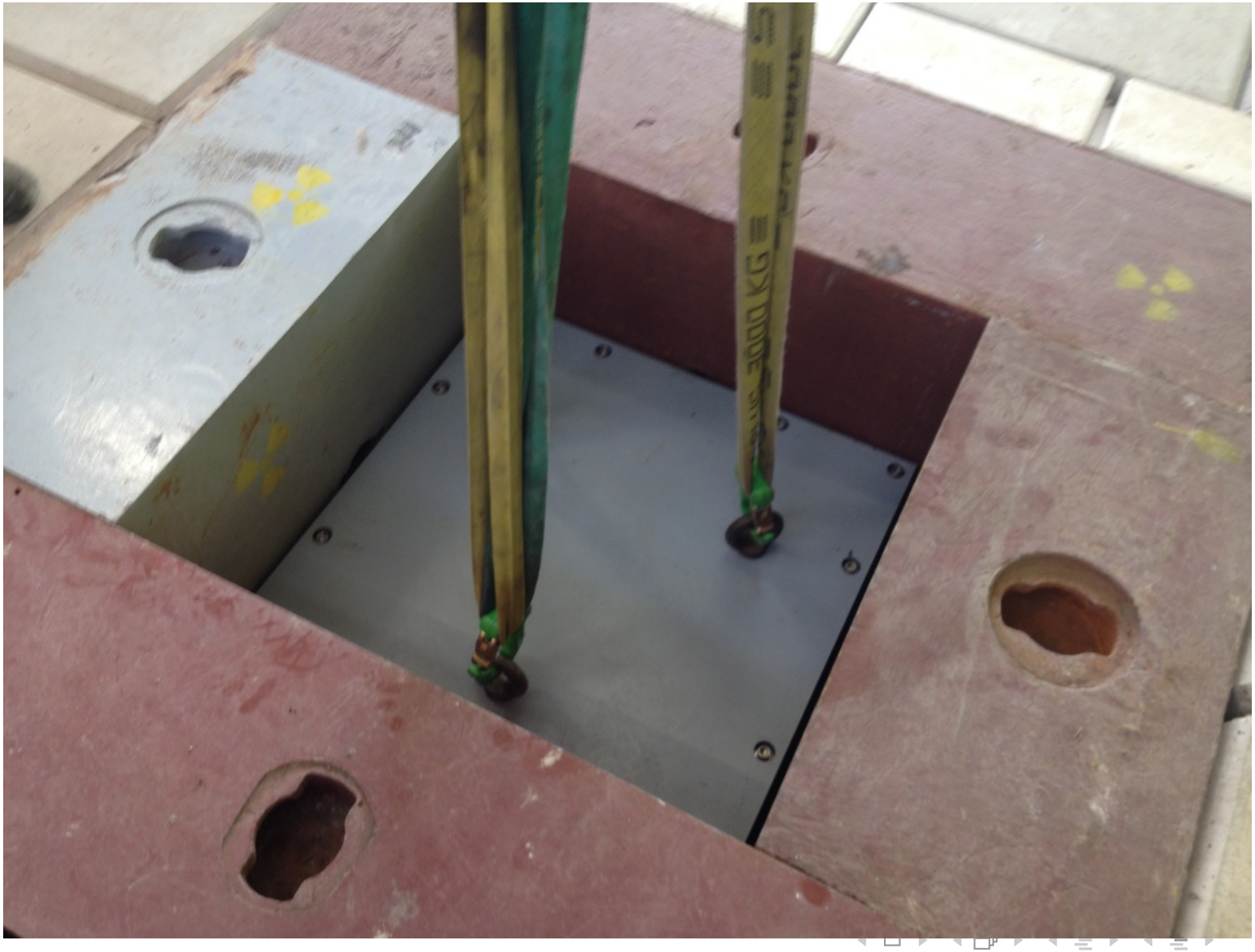
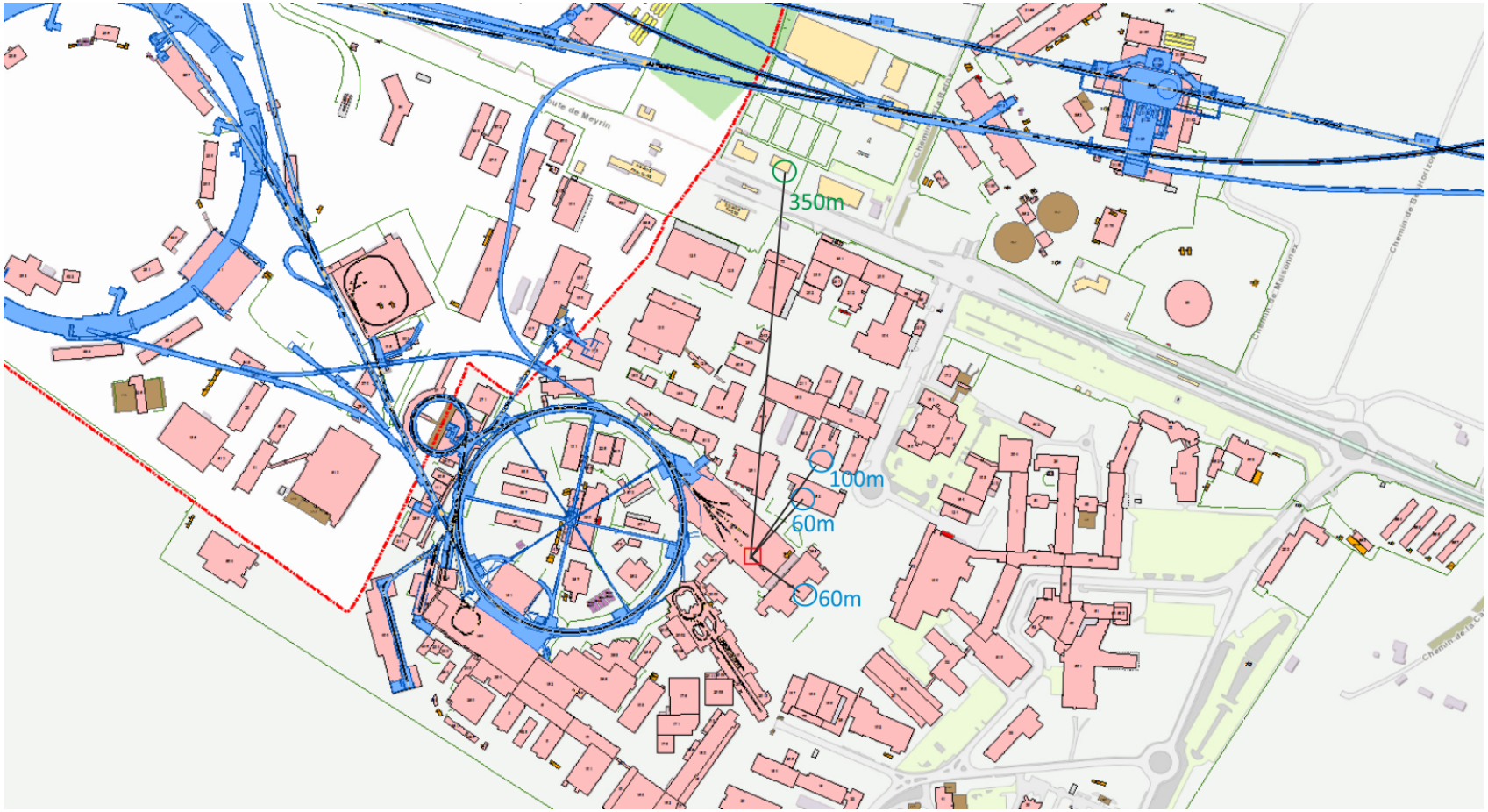


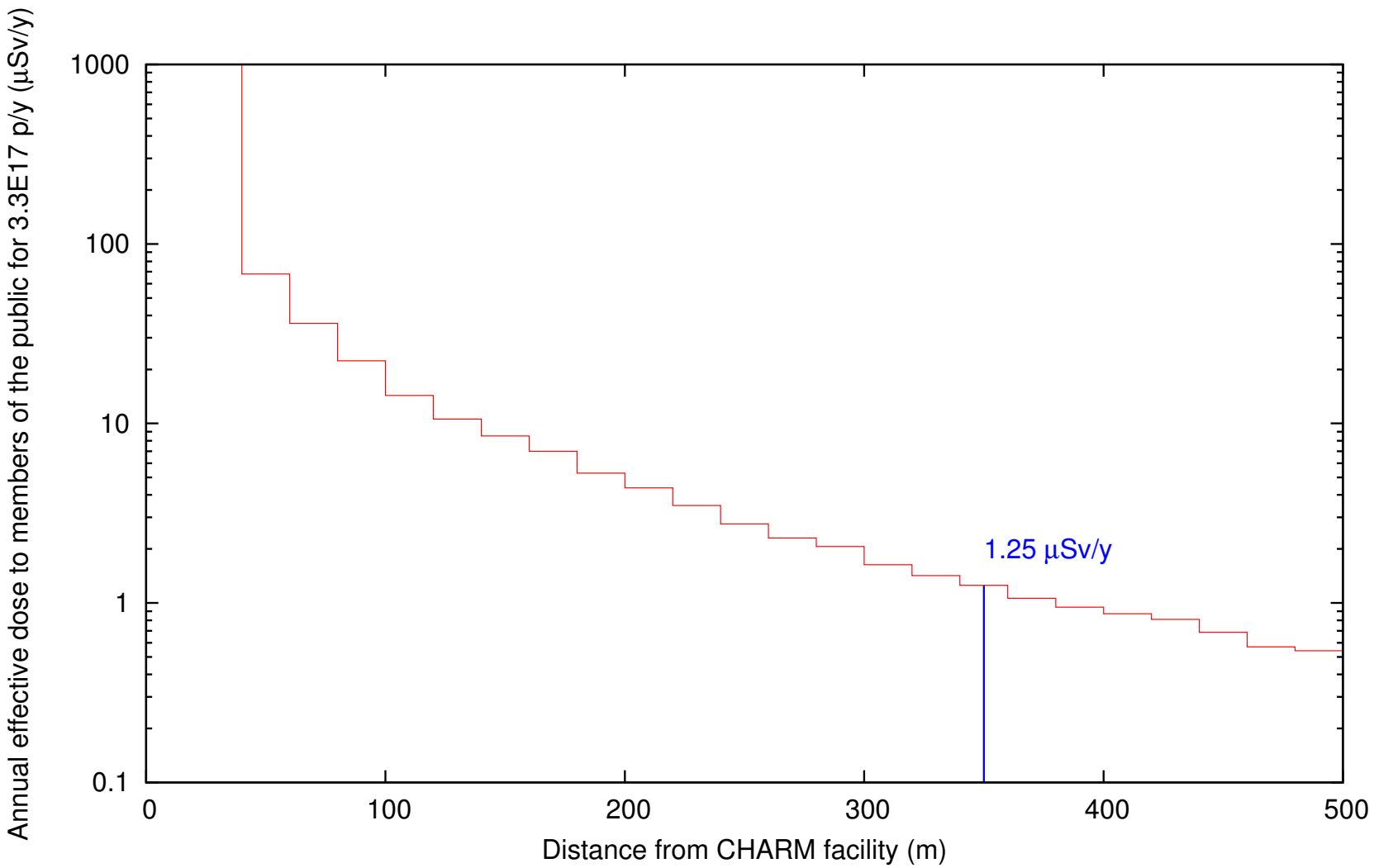
Prompt Radiation – Design Goals

- **Area Classification:**
  - 3 μSv/h (control rooms) or 15 μSv/h (low occupancy area) at 40 cm outside from shielding walls for maximum average beam intensity
  - 2.5 μSv/h outside of the hall for maximum average beam intensity
  - Optimization of shielding passages (Access chicanes, ventilation ducts, cable ducts)
- **Sky-shine:** 1 μSv/y to members of the public (reference group) for nominal/maximum annual protons on target
- **Monitoring:** Define locations for area monitors
- **Shielding design:**
  - Re–use of existing concrete and iron blocks
  - Space constraints due to already existing facilities/crane
- **Monte Carlo simulations:** performed with **FLUKA**
  - Configuration management and synchronization with CAD integration model

Sky-shine



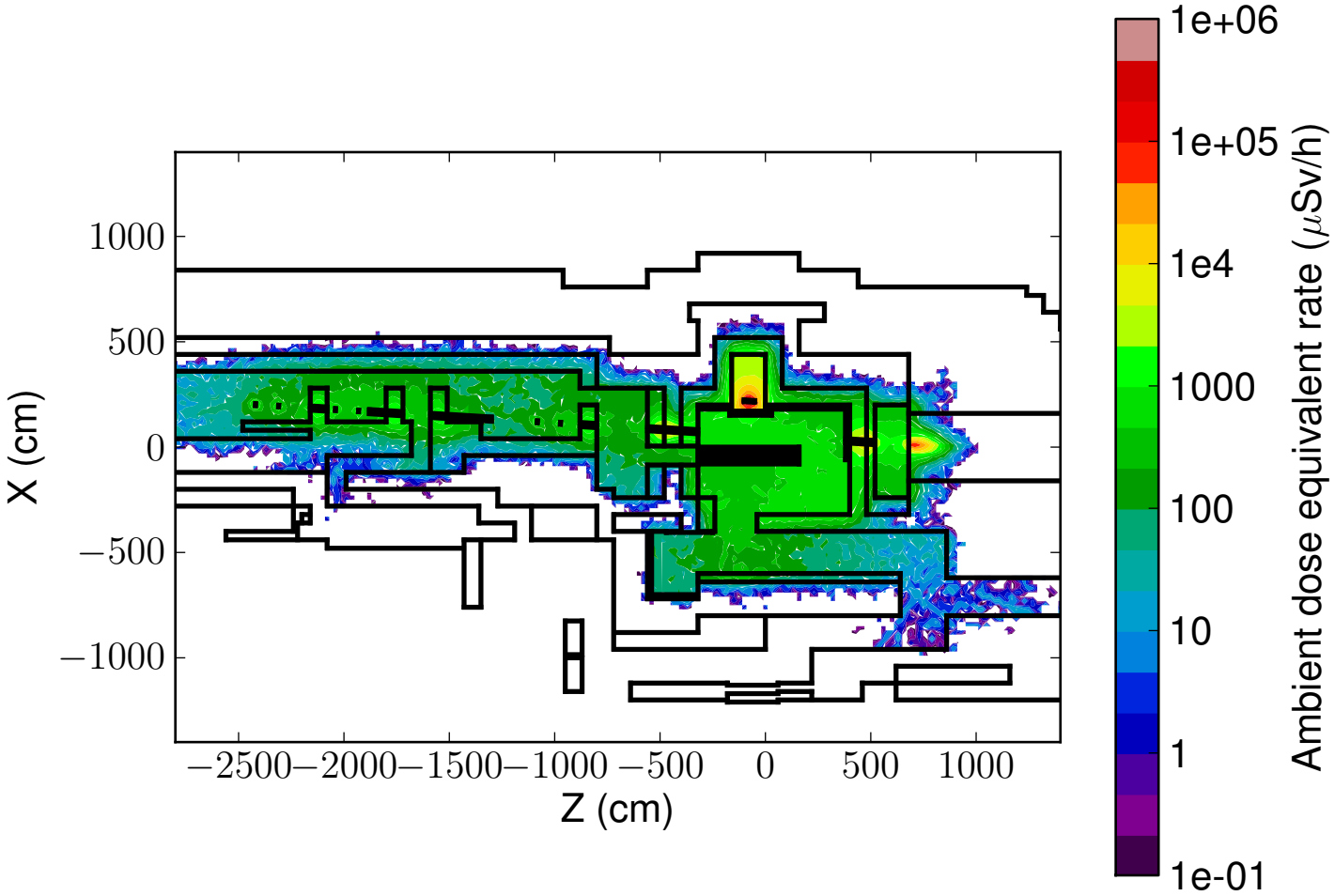
Sky-shine – Annual effective dose to members of the public



Residual Radiation – Design Goals

- Reduce ambient residual radiation
  - Optimization (ALARA)
  - More efficient exploitation of facility
- Marble cover for some wall parts and ceiling
- Target alcove
  - Target moved to alcove during access
  - Movable marble shielding to close alcove
- Studies for different shielding configurations to optimize procedures
- 100 μSv/h for the Patch Panel area (most frequent access)
- **Monte Carlo simulations:** performed with **FLUKA** and **DORIAN** code

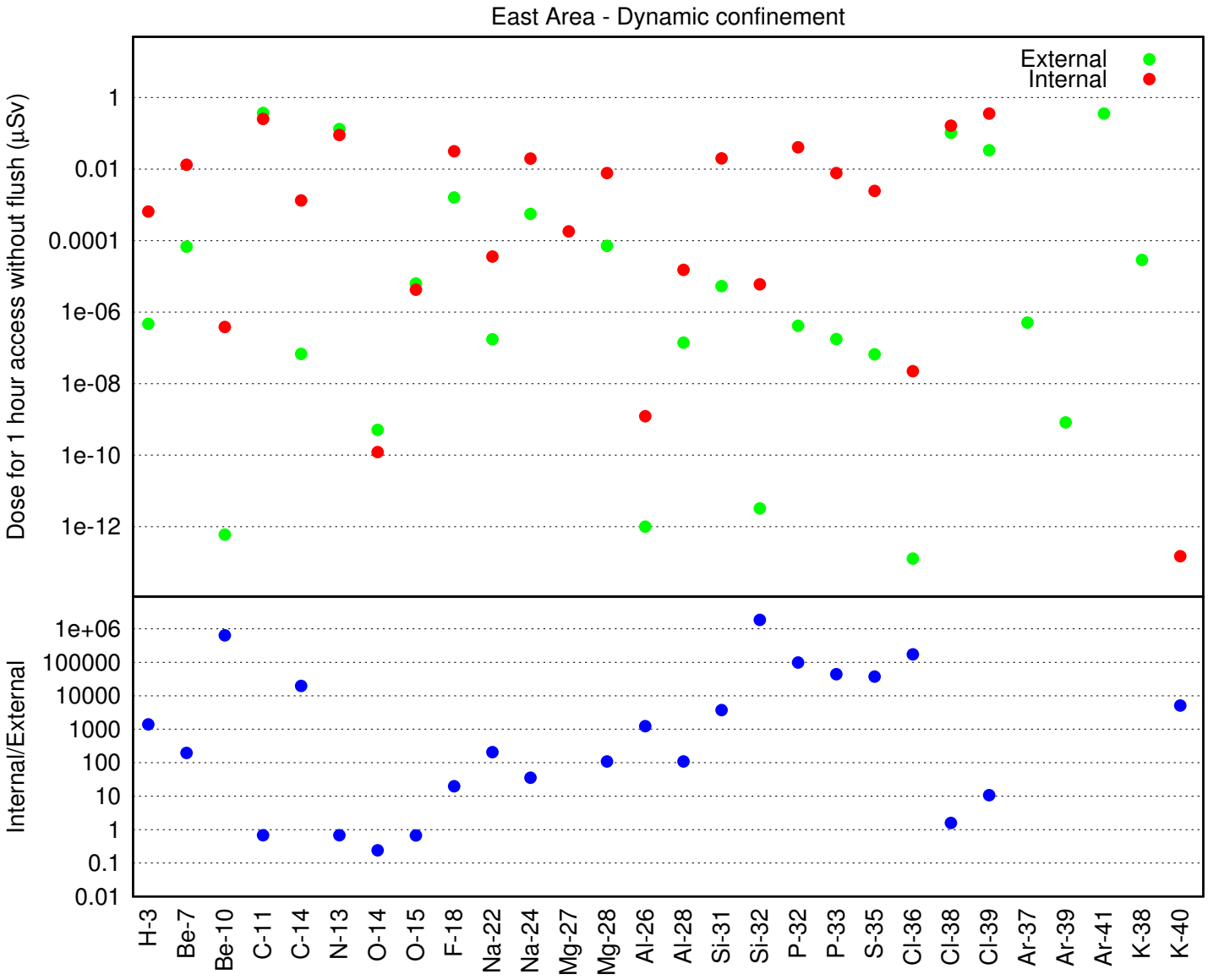
Residual DR after 200 days with 6.6E10 p/s and 1d of cool–down



Air Activation – Methodology

- Design goals
  1. Committed effective dose due to inhalation:
     $\leq 1\,\mu$Sv for 1 hour access
  2. Effective dose to members of the public (reference group):
     $\leq 1\,\mu$Sv/y
- Radionuclide concentrations and release
  - Track-length spectra scored in air volumes
  - Radionuclide production yields by weighting of spectra with dedicated air activation cross–sections
  - Confinement characteristics (dynamic/static) and time evolution to obtain radionuclide concentrations
  - No filtering of the recirculated air has been taken into account
  - External effective dose and the internal committed effective dose by integrating over the 1 hour exposure time after a cool-down period of 30 minutes without flush before access
  - External effective dose to members of the public by dedicated Monte Carlo integration program (**EDARA**)

Air Activation – Access



Air Activation – Access